HYDROGEN POWERED HYBRID WING BODY FREIGHTER SYSTEMS ANALYSIS AND CONCEPTUAL DESIGN USING THE ACS TOOL

BY

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THESIS

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ABSTRACT

This study explores the Systems Engineering involved in creating an environmentally green system for transporting cargo using aircraft. The study looked at using hydrogen and the resulting infrastructure to allow the system to function. The functionalities and then subsystems were defined for the aircraft that would be used by the system. After the level 0 Green Cargo Transport system was investigated, the level 1 flight system was investigated in a similar fashion. The functionalities and then subsystems were defined for the aircraft that would be used by the aircraft to fulfil the necessary functions of the level 0 system. Hydrogen fuel was investigated as the source of energy for the flight. The Aircraft Synthesis (ACS) tool from AVID was utilized to quickly run missions and design for a hydrogen powered aircraft vs. a Jet-A powered aircraft. The Hydrogen powered aircraft, while requiring a heavier fuel system, had a significantly lower takeoff weight than the Jet-A aircraft. The Hydrogen fuel was much lighter because the specific energy is much higher than Jet-A. However, hydrogen is much less dense than Jet-A, and as a result a higher aircraft volume was needed. A Hybrid Wing Body was approximated in ACS because of the excess volume in that particular configuration. That made a HWB an attractive candidate for hydrogen fuel. The hydrogen candidate was scaled down to two additional sized to accomplish the function of flying city to city; this is accomplished by enabling as many airports as possible. The mid-sized and small sizes had reduced Balanced Field Lengths allowing many airports to be serviced. Ultimately the Hydrogen powered option is cleaner and lighter, allowing for environmentally friendly transport of cargo.

ACKNOWLEDGEMENTS

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TERMS/ACRONYMS

FAA	Federal Aviation Administration
ATC	Air Traffic Control
NO_x	Generic term for mono-nitrogen oxides NO and NO_2
DOE	Department of Energy
SOS	System of Systems, Refers to level 0 System
XX (or YY)	Used to refer to a number not yet defined
TBD	To Be Determined. Similar to the use of XX or YY
GPS	Global Positioning Satellite
HWB	Hybrid Wing Body design
ECS	Environmental Control System
RFID	Radio-frequency identification
MTOW	Maximum Takeoff Weight
UAV	Unmanned Aerial Vehicle
FADEC	Full authority digital engine (or electronics) control
SSET	Space Shuttle External Tank
NASA	National Aeronautics and Space Administration
ACS	AirCraft Synthesis
C_{L0}	Zero angle of attack lift Coefficient
Jet-A	Kerosene based Jet fuel
H_2	Hydrogen
HALE	High Altitude Long Endurance
OPR	Overall Pressure Ratio
SFC	Specific Fuel Consumption
UHC	Unburned HydroCarbons

1. CHAPTER 1: SYSTEM OVERVIEW LEVEL 0

1.1. Objective statement

To develop a system to enable point to point cargo transport while reducing emissions of renewable fuels.

The burning of fossil fuels creates pollutants that are released into the atmosphere. This study aims to create a system that would greatly reduce the pollutants while still able to enable point to point cargo transport. Currently the infrastructure for cargo transport run on fossil fuels, but the fossil fuel reserves will be depleted eventually. To avoid this in the new design the fuel source must be one that is renewable so to avoid a necessary infrastructure change in the future like the one we are facing right now.

1.2. OV-1

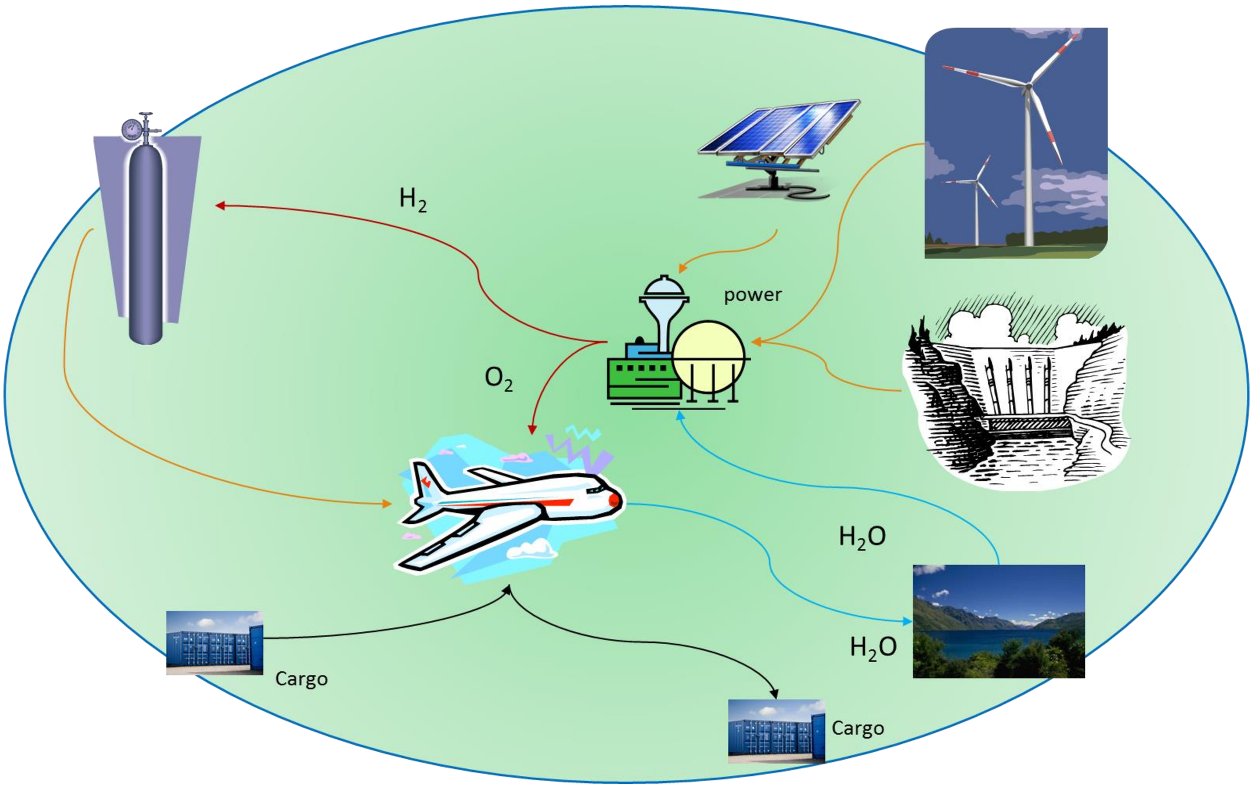

Figure 1: OV-1

This diagram shows the operations of the System from energy harvesting to the combustion of hydrogen.

1.3. Description

The Green Transport System is a System to be used in the transport of cargo using aircraft. The goal of the system is to increase efficiency of the cargo system by enabling a more direct route via aircraft while reducing emission created by the system. The need for more Green travel will only increase as the air and automotive traffic increases. One of contributors to both air and ground traffic/emissions is the aircraft and diesel trucks used to execute on a hub and spoke design. A chart summarizing the hub and spoke design and the possible change introduced by the Green Cargo Transport System is shown below.

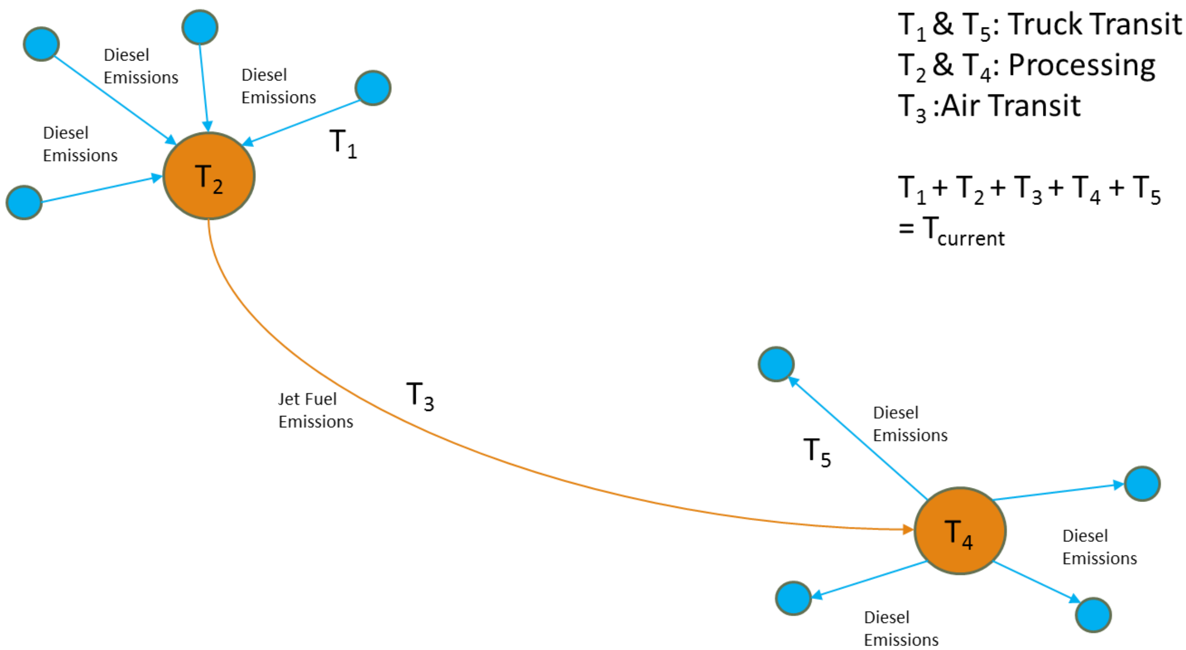

Figure 2: Current Hub And Spoke Diagram

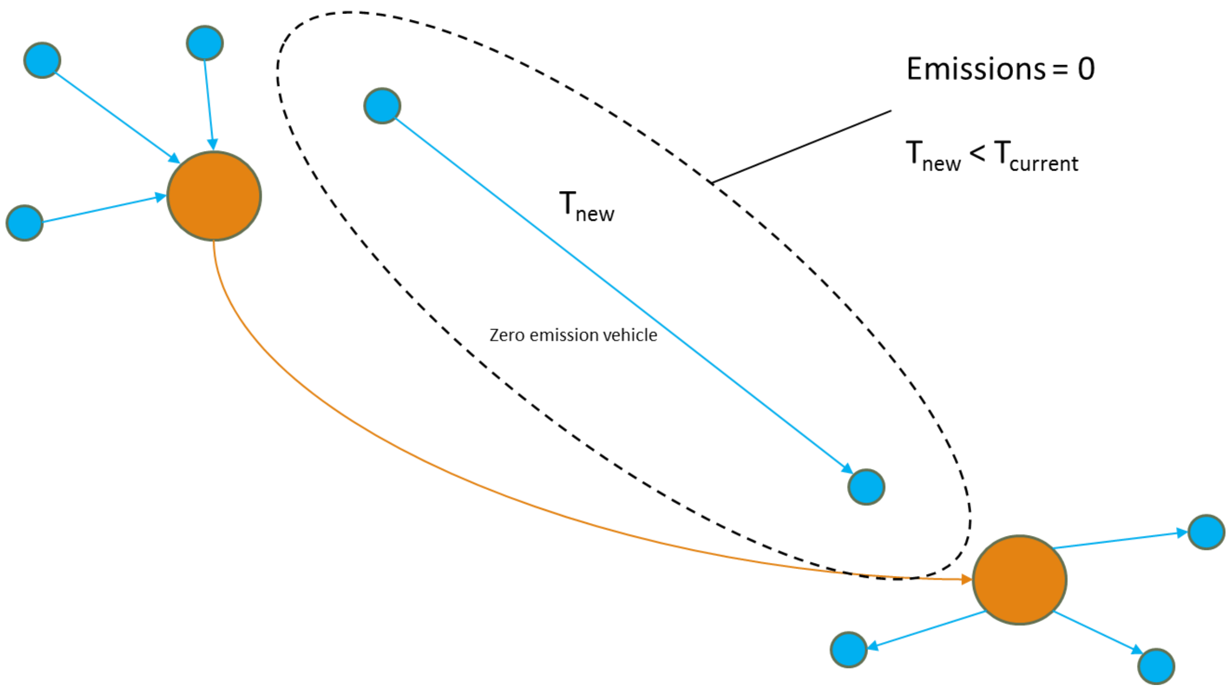

Figure 3: Potential Point to Point Design

In the first scenario the hub and spoke design takes packages from a town and delivers them to the closest hub. The cargo is then taken from hub to hub, and delivered to the destination town. These time components, in addition to the processing time, add up and give the time of transit.

In the new point to point travel system the time and distance could be reduced in many case by flying direct if possible. While this may not always be possible, it offers some increases in time efficiency and the decreased distance would reduce emissions. Figure 3 shows the ideal case in which a zero emissions vehicle would fly direct.

This study will focus on hydrogen as the fuel source because of its potential as a zero emissions fuel source, its reusability, and its abundance and availability. Energy generation systems will allow for electrical energy to be produced or harvested and transmitted to the system. This energy can be used to separate hydrogen and oxygen in water. This energy system, utilizing green energy such as wind or solar, can have minimal emissions and environmental impact. Access and acquisition of water in order to extract hydrogen for use as a fuel source will be a necessity, and this could be a limiting factor in some climates. The water will be collected and transported using energy sources that minimalize emissions and environmental impact. The resulting hydrogen will be transported to the necessary locations. The Green transport system aircraft, using hydrogen, carries cargo from airport to airport. Specialized cargo equipment will load the cargo on and off the aircraft. The aircraft will comply with Air Traffic Control, Ground Control and Airport Authority directions as well as FAA regulations while minimalizing the need for human interaction or intervention. Because of the desire to increase efficiency, automation will play an important role in loading/unloading cargo, and the flying and piloting of the aircraft. The Green transport system will also make use of ground support crews to support the aircraft.

The System includes the energy/power systems involved in the acquisition of electrical energy. Including the cost, setup, and land required. Although the end desire is for the energy systems to be fully green and independent, the System may begin operation by buying the necessary energy and transitioning to the other sources as a tiered development. The System includes the systems responsible for acquiring water and all the energy needed to run that system. The system includes the extraction and transportation of hydrogen. This includes any special airport setup and space needed. Some airports will require a maintenance facility, while other more remote locations will only require fuel stores. The System includes the entire fleet of aircraft that transport the cargo. The System includes any and all equipment needed to support the aircraft, including special fuel transfer, specialized cargo equipment, and any other specialized maintenance. The system does not includes the specific contents of the cargo or what service is using the system. The System also does not include pre or post-airport cargo transport or handling.

Electrical Energy is a primary input to the Green Transport Fuel System. This energy could come from a number of different sources, and will be used as a primary resource throughout the System. Water will serve as another primary input in the processing of hydrogen. Cargo will be input from the customers using the System. Inputs from the ATC will also affect the System.

The Systems main output will be cargo to the destination city. The System also outputs gaseous water to the atmosphere. The fuel extraction also releases gaseous oxygen, this may form into ozone as well. In electrolysis of water with an electrolyte, other gases may be an output.

The main product of this System is the transport via air travel from one city to another. Water emitted from the engine by burning hydrogen will be another product.

A byproduct from the System include excess energy from the power generation. This excess energy could be stored or sold. NO_x and other emissions are possible from the engines during flight. Contrails from gaseous water are also possible for byproducts. Any gases from the electrolysis process are also potential by products. Gases such as oxygen, fluorine, and chlorine could be liquefied and sold.

Capabilities:

The System will be able to generate hydrogen gas from water and then convert it to liquid form. The liquid fuel will be able to be transported to where it is needed. The Systems final mature form will be able to provide electrical power to all components of the System without the use of fossil fuels. Before then some energy may be bought based on system maturation and location. The systems will be able to transport cargo between cities with airport runways >5000ft. The System will be able to load and unload cargo from the aircraft and from the other means of cargo transport (truck, train, or boat). The system will be able to generate hydrogen from water. The system will be able of dispelling or monetizing the other gases created in the generation of hydrogen. The system will be able to operate within the National Airspace, complying with airport authorities, ground control, ATC, and associated FAA regulations. The System will be able to handle a range of payloads the upper limit being 45,000lbs. The System will be able to handle a range of internal cargo space the upper limit being 5,000 ft^3. The System will be able to handle a different ranges for different aircraft sizes the upper limit being 4000 nmi. The System will be able to travel at low transonic speeds: ~Mach 0.75.

1.4. CONOPS

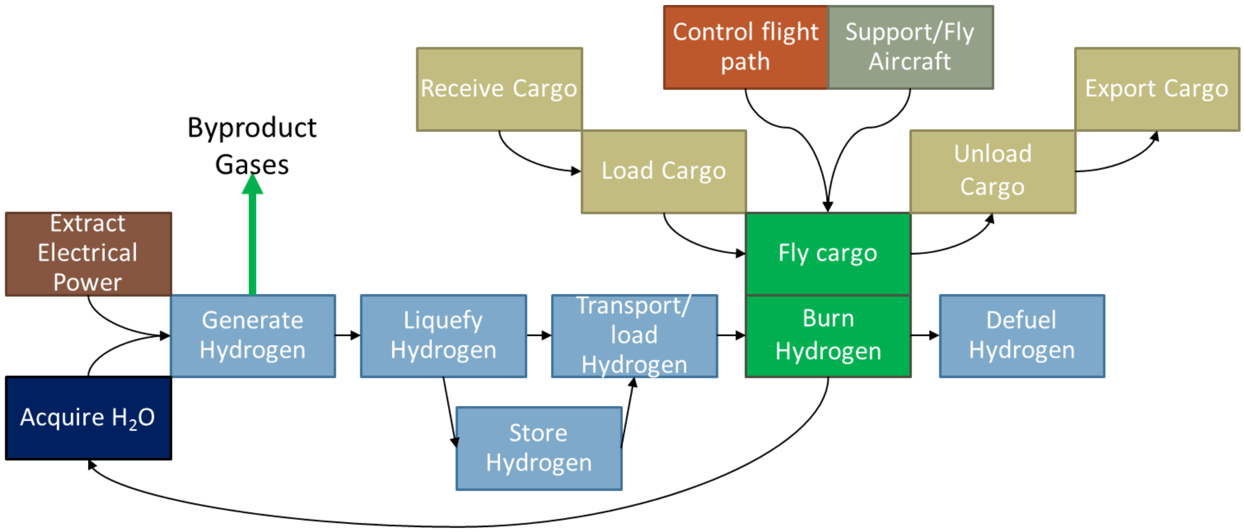

Figure 4: Concept of operations

This diagram shows the operations of the System. All major aspects of the System functions are represented here to show the big picture flow of the System. These flows are expanded in the next section.

1.4.1. Functional sequence diagrams

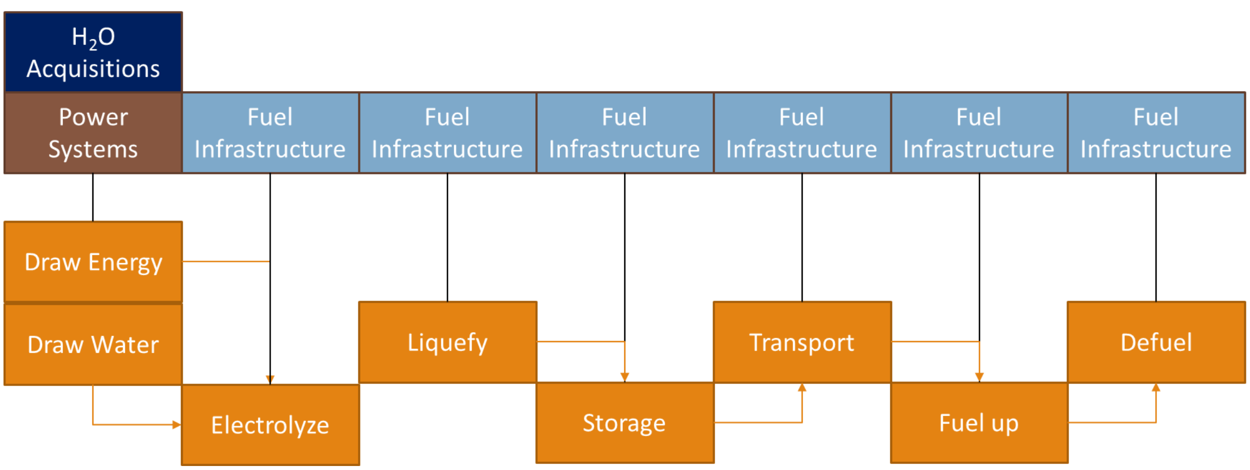

Figure 5: Fuel System Function sequence diagram

This first functional sequence diagram shows the functional flow in the production of the fuel used for air transport. The Power system is involved at the first step: “Draw Energy”.   Then Water most be acquired, and the rest of the process uses the fuel infrastructure to create and transfer the fuel. This is also an ideal mature system. In some locations, and at early development the hydrogen may be bought or acquired from a different process. In this process the water would be brought in and electrolyzed using the energy from the Power Systems. If an electrolyte is used the two gases produced will be hydrogen and some other by product such as chlorine. If no electrolyte is used then the resulting gasses will be hydrogen and oxygen. The hydrogen will then be liquefied and transported or stored. When the hydrogen reaches the aircraft the fuel will be transferred onboard to be burned and unused fuel may be removed and placed in storage or used in another aircraft.

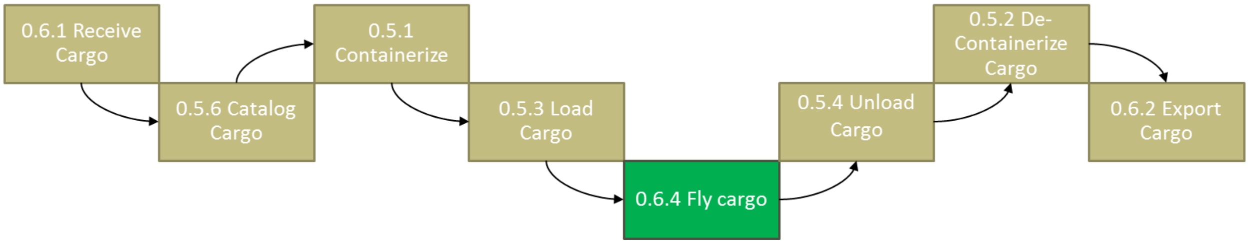

Figure 6: Cargo System Function sequence diagram

In this diagram the cargo systems and flight systems are represented to show the way cargo is transfer from one location to another. The Cargo system itself is responsible for all the cargo support but very little of the cargo transport. The cargo system receives and export cargo but also is capable of cataloging that cargo for tracking and other important data needs.

1.5. Functional breakdown

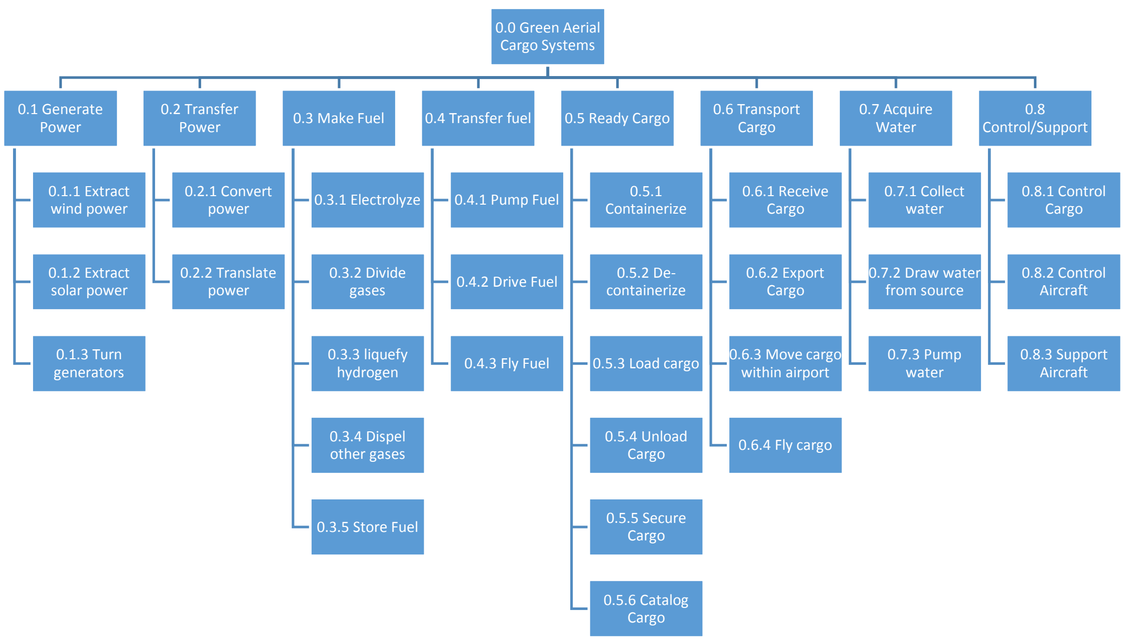

Figure 7: System Functional breakdown diagram

The functional breakdown of the system is drawn from the concept of operations and OV-1 as well as the system description. The functions identified are the following:

0.1. Generate power: this function includes the use of any and all fuel sources so long as they comply with the capabilities and requirements (must not use fossil fuels)

0.2. Transfer power: this function includes the modification of power (transformers) and movement of power (wires, batteries, fuel cells)

0.3. Make fuel: using the power acquired and transferred to form fuel from water, this also includes any post processing (compressing, liquefaction) of the fuel.

0.4. Transfer fuel: this function could include: driving, pumping, dumping, etc. It results in the movement of the fuel from its location to the next desired location.

0.5. Load/unload cargo: this function includes physically moving the cargo to the cargo carrying vessels (aircraft, trucks), and also the labeling and cataloging of cargo.

0.6. Transport Cargo: The physical motion of the cargo from start to end destination. As this is a Green Aerial Cargo Transport. This would also include takeoff, cruise, and landing as sub functions.

0.7. Acquire Water: drawing, transferring, or transporting water (liquid or otherwise) to the desired location to extract the hydrogen fuel.

0.8. Control: this is the electronic, analog, or even verbal controls of the cargo as in flows in and out. This also is used to control the aircraft in flight, taxi, loiter, landing, and takeoff.

1.6. Product structure

	0.1 Generate Power	0.1.1 Extract Wind Power	0.1.2 Extract Solar Power	0.1.3 Turn Generators	**0.2 Transfer Power**	0.2.1 Convert Power	0.2.2 Translate Power	**0.3 Make Fuel**	0.3.1 Electrolyze	0.3.2 Divide Gases	0.3.3 Liquify Hydrogen	0.3.4 Dispel Other Gases	0.3.5 Store Fuel	**0.4 Transfer Fuel**	0.4.1 Pump Fuel	0.4.2 Drive Fuel	0.4.3 Fly Fuel	**0.5 Ready Cargo**	0.5.1 Containerize	0.5.2 De-containerize	0.5.3 Load Cargo	0.5.4 Unload Cargo	0.5.5 Secure Cargo	0.5.6 Catalog Cargo	**0.6 Transport Cargo**	0.6.1 Receive Cargo	0.6.2 Export Cargo	0.6.3 Move Cargo Within Airport	0.6.4 Fly Cargo	**0.7 Acquire Water**	0.7.1 Collect Water	0.7.2 Draw Water From Source	0.7.3 Pump Water	**0.8 Control/Support**	0.8.1 Control Cargo	0.8.2 Control Aircraft	0.8.3 Support Aircraft
POWER	x	x	x	x	x	x	x	x	x		x	x		x	x															x			x				
FUEL								x	x	x	x	x	x	x	x	x	x																				
H20								x	x																					x	x	x	x				
FLIGHT																	x												x							x	
CARGO																		x	x	x	x	x	x	x		x	x	x							x		
GROUND SUPPORT																x																					x
CONTROLS/COMPLIANCE																								x		x	x							x	x	x	

Figure 8: Product-Function Allocation

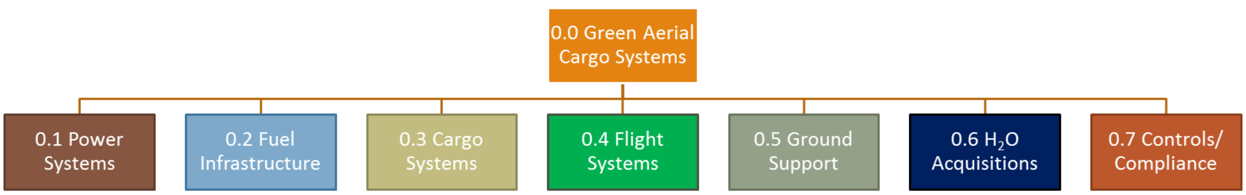

Figure 9: Product Structure diagram

From the functional structure seven products or sub-systems were identified to perform all the necessary functions:

0.1. Power systems: this sub-system is responsible for generating and transferring green energy for the production of Fuel, and the electrical needs of all other ground based systems such as: H_2O acquisitions, Ground support, and cargo systems

0.2. Fuel Infrastructure: this system includes the production, modification and distribution of hydrogen fuel. This would include tubes, condensers, pumps, trucks, etc.

0.3. Cargo Systems: this is a specialized support system for the loading and unloading of cargo. In this system would be the trucks and loaders used to load and unload. Also in this system is the computers and scanning equipment in order to catalog and tag each piece of cargo.

0.4. Flight Systems: this system is the system responsible for moving the cargo. This includes the aircraft fleet and all sub-systems.

0.5. Ground support: this is the maintenance and support system for the aircraft. This includes maintenance for the aircraft, and any standard support equipment and peculiar support equipment.

0.6. H_2O acquisitions: this is the system responsible for supplying the fuel system with the water to create fuel. This system includes any wells, pumps, distilleries, etc.

0.7. Controls/Compliance: this system includes all interaction and compliance with FAA and ATC regulations.

1.7. Diagrams

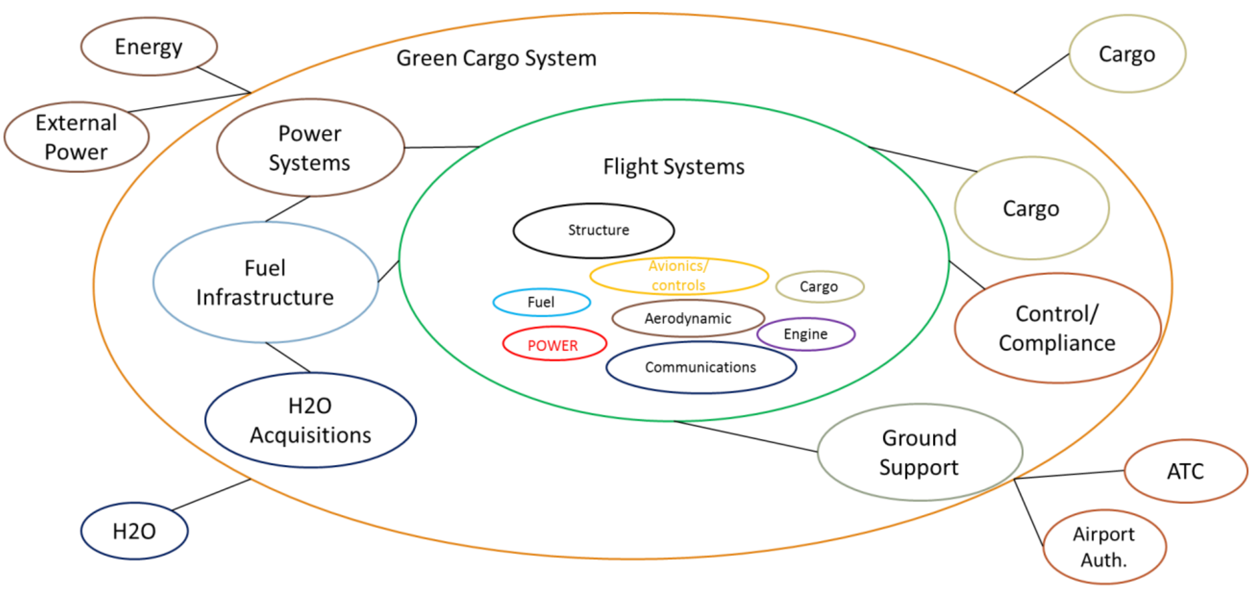

Figure 10: SOS Context Diagram

The context diagram shows the boundaries and some relationships between systems. Energy come in as an outside input to the system from wind, sun, or other energy forms. External power also may be utilized. This would be used in a case in which the Power Systems had not been developed yet or if the area were more remote. Water also touches the system through the H_2O acquisitions. Cargo from outside the system touches the system via the Cargo System. ATC, Airport Authority, and other control entities also touch the system. The flight system has interfaces to most of the other systems as it is the method of transport for the cargo, and is at the center of the diagram.

1.8. Interfaces

	POWER	FUEL	H20	FLIGHT	CARGO	GROUND SUPPORT	ATC
POWER		**X**	**X**	**X**	**X**	**X**	
FUEL			**X**	**X**			
H20							
FLIGHT					**X**	**X**	**X**
CARGO						**X**	
GROUND SUPPORT							**X**
ATC							

Figure 11: SOS Interface Diagram

The above figure shows all the interfaces for the System. Flight and power systems have the most connections whereas ATC interfaces only with the Flight system and the Ground support

1.9. N2 diagrams

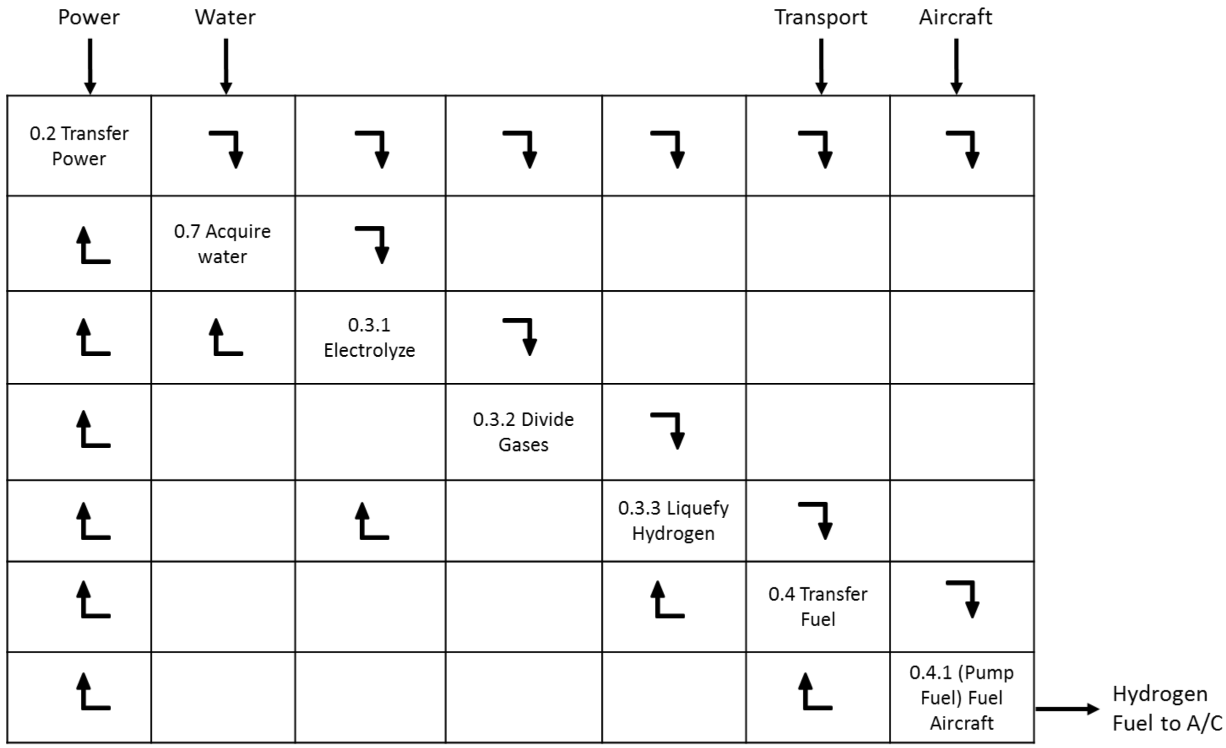

Figure 12: Fuel Creation N2 Diagram

The above diagram shows the functions and their relationships in the production of fuel. External inputs of power (energy from wind, sun, etc.) comes in at step one: transfer power. Power system has power requests coming in and energy going out for each function. For example, the power is transferred to the water system for the pumping and any cleaning of the water. The acquire water function provides a feedback to the transfer power function requesting the power it needs. A similar process is done for the other transfer power interfaces and feedbacks to the other functions. Water is acquired in step two. This water is provided to the electrolyze function with a feedback for requesting water as the water is electrolyzed. In step three, the water is electrolyzed and the resulting gases are provided for division. In step four the gases are divided. The hydrogen is then passed to the liquefy function. The liquefying provides liquid fuel to the Transfer Fuel function, and requests more hydrogen as a feed back to the electrolyze function. The fuel is transferred providing a feedback to the liquefaction process as a request for more liquid fuel. Transport comes in as an external input after the fuel has been made and liquefied. In the last step the fuel is transferred to the aircraft. The final output is fuel to the aircraft itself.

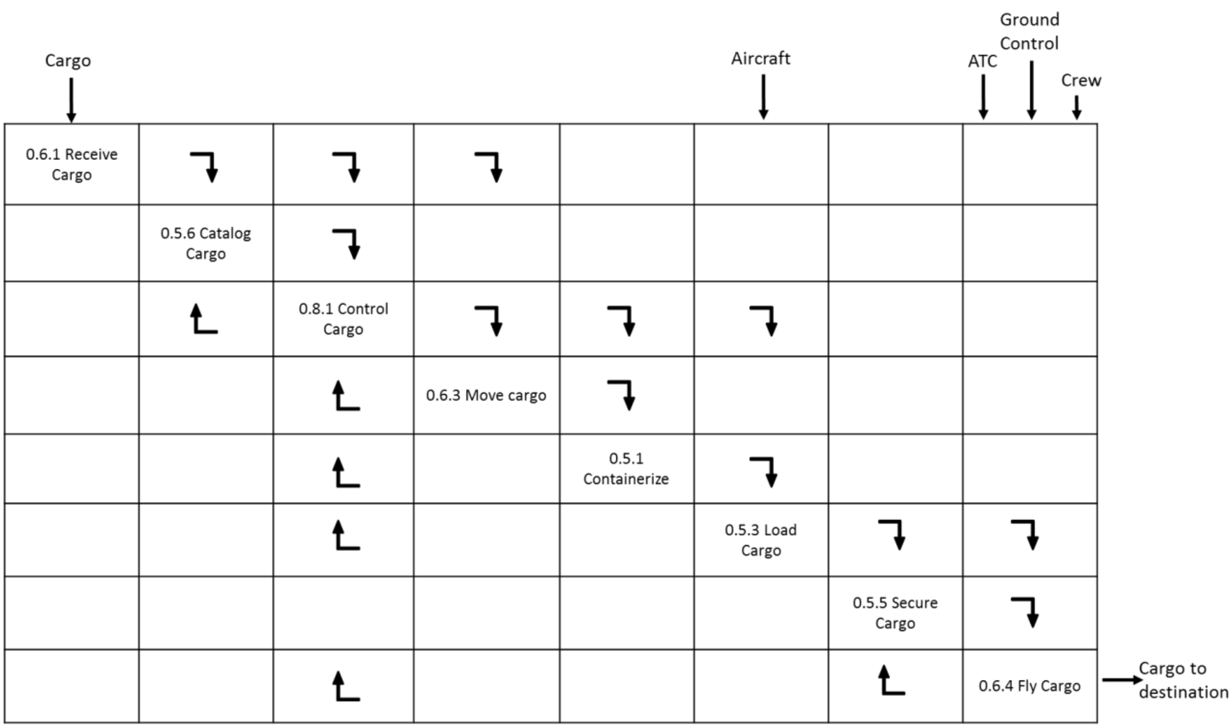

Figure 13: Load Cargo N2 Diagram

This N2 diagram outlines the functions and their relationships in cargo transportation from receiving the cargo to taking off for the next location. Acquiring cargo is an input at step one. As the cargo is received it is an input for cataloging and control. The second step catalogs all of the pertinent details of the cargo and records it. These details serve as an input to the cargo control. This control makes sure each package finds its correct location throughout the journey. The control function may send feedback to the cataloging process if something needs to be changed. After these steps the cargo is moved within the facility to its proper locations. Once the cargo is moved, the cargo is containerized. All this information is fed back to the control function. As the cargo is loaded, the aircraft is input into the process. The cargo is secured to the airframe, and the cargo is flown to the next destination.

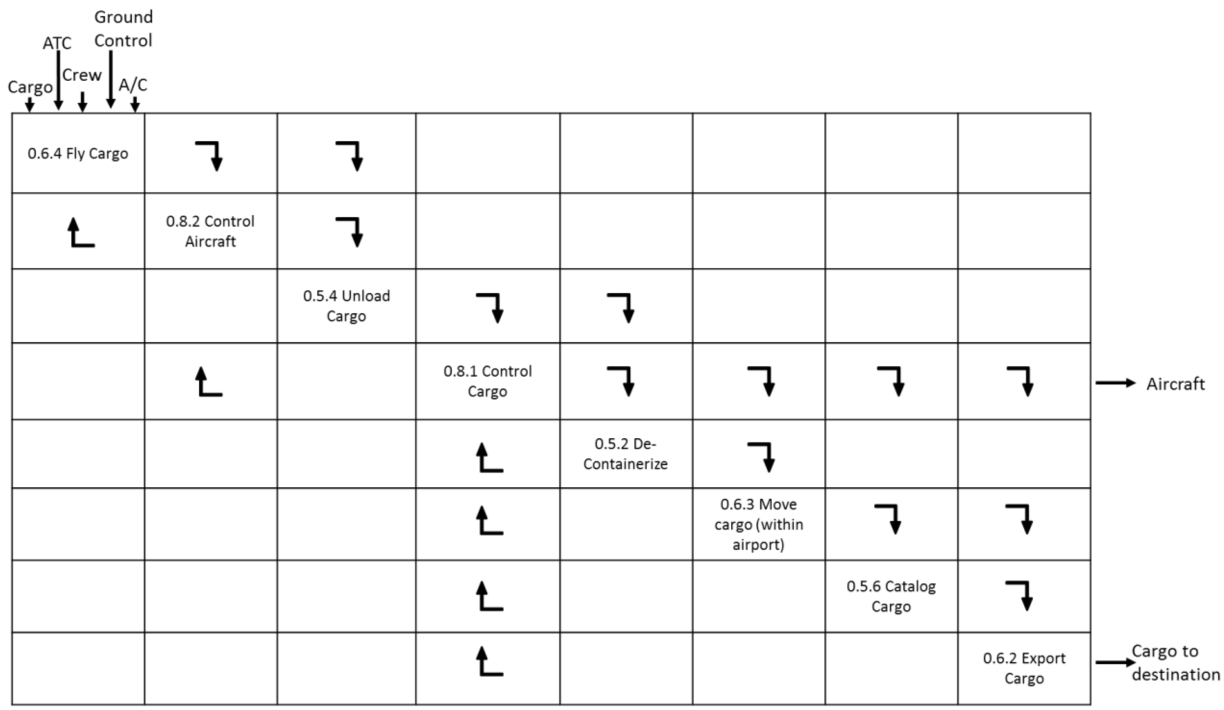

Figure 14: Unload Cargo N2 Diagram

This N2 diagram shows the process of unloading the cargo from the aircraft and exporting to the desired final location. Cargo, the Aircraft, the Crew, Ground Control, and ATC enter as inputs to the first step which is to fly the aircraft. To the destination. This in an input to the next step which is to control the aircraft, which provides a feedback of control inputs and headings to the Fly function. The fly cargo function also provide an input to the unload function. Once unloaded the cargo is then an input to control and to de-containerize functions. The control function provide a feed back to the control aircraft function to confirm the aircraft is able to move on to the next task. The control cargo function provides control to the rest of the functions and they send feed back to the control. After De-containerizing, the cargo is moved within the airport and cataloged. Finally the cargo is exported and taken to the final destination.

1.10. Top Level Requirements

Product	Function	Req. No	Requirement	Rationale
0.0	0.0	00-001	The System Shall reduce the emissions compared to the current system	The goal of this system is to be green in its operation
0.0	0.0	00-002	The System Shall fulfill all of the capabilities of the current system	The new System must take the place of the existing system and fulfill all of the demand of that system
0.0	0.0	00-003	The System operational costs Shall be competitive with the current systems costs	The operation costs cannot exceed the current cost by too much lest the option not be fiscally feasible
0.0	0.0	00-004	The System Implementation costs Shall be affordable	This is a cost requirement that will be set based on government funding and subsidies.
0.0	0.0	00-005	The System's manned labor Shall be less than the current system's	The System must be automated enough to require only half the manned labor.
0.0	0.0	00-006	The System Must meet all DOE and FAA regulations	The system has to be compatible with the regulations in place.

Table 1: Level 0 Top Level Requirements

1.11. Sub-system Requirements

Product	Function	Req. No	Requirement	Rationale
0.1	0.1	00-007	The Power System Shall be capable of operation without the use fossil fuels	Necessary for green operation
0.1	0.2	00-008	The Power System Shall be capable of providing electrical power for local ground based systems	Each site may be different but the power system needs to be the source of power for ground systems where airport power is unavailable or insufficient
0.2	0.3	00-009	The Fuel Infrastructure Shall produce liquid hydrogen fuel from water for use in the aircraft	The fuel infrastructure is needed to produce the fuel from power and water for use in the aircraft
0.2	0.4	00-010	The Fuel Infrastructure Shall provide a means to deliver the fuel from the location of production to the fuel tanks of the aircraft	The fuel system in responsible for physically getting the fuel to the airport, and into the aircraft.
0.3	0.5	00-011	The Cargo System Shall Load and Unload the cargo from all stages of the journey	The Cargo must be physically loaded and unloaded
0.3	0.8	00-012	The Cargo System Shall track the location of individual packages throughout the journey	The Cargo System allows users to track packages and collect data.
0.4	0.6.4	00-013	The Flight System Shall use Hydrogen as the source of fuel	This allows green operation
0.4	0.6.4	00-014	The Flight System Shall be Capable of Unpiloted Flight	This will help allow the manned labor to be reduced. It also reduces pilot error.
0.4	0.6.4	00-015	The Flight System Shall be Capable of piloted Flight	This allows ferrying of personnel, and allows pilots to monitor the unmanned systems for redundancy and verification.

Table 2: Level 0 Subsystem Requirements

0.5	0.8.3	00-016	The Ground Support System Shall perform all the maintenance for the Flight system	Aircraft need maintenance and that is one of the major components of the ground support. This may be in a major maintenance hub, down to a routine check at a remote location
0.7	0.8.2	00-017	The Controls/Compliance System Shall be able to control the aircraft.	This allows unmanned operation
0.6	0.7	00-018	The H_2O Acquisition System Shall provide Water to the Fuel Infrastructure	The Fuel infrastructure needs the water to create hydrogen fuel.
0.7	0.8.2	00-019	The Controls/Compliance system Shall interface and comply with all ATC and FAA regulations	This system needs to interface heavily with current restrictions and regulations

Table 2 (Cont.)

1.12. Interface Requirements

Product	Function	Req. No	Requirement	Rationale
0.1-0.2	0.2-0.3	00-020	The Power System Shall Provide XX kW to the Fuel Infrastructure	Power for Fuel creation and transport
0.1-0.6	0.2-0.7	00-021	The Power System Shall Provide XX kW to the H_2O Acquisition	Power for Water draw and transport
0.1-0.5	0.2-0.8.3	00-022	The Power System Shall Provide XX kW to the Ground Support	Power to run ground support Avionics and equipment. (May not be required in airports that provide power).
0.1-0.3	0.2-0.5/0.6	00-023	The Power System Shall Provide XX kW to the Cargo System	Power for cargo transport and loading. (May not be required in airports that provide power).
0.2-0.4	0.4-0.6.4	00-024	The Fuel Infrastructure Shall have equipment for transferring the fuel to the Aircraft in less than XX minutes	With non-standard fuel it is important that the fuel infrastructure is able to effective and rapidly move the fuel to the aircraft
0.3-0.4	0.5-0.6.4	00-025	The Cargo System Shall have equipment to Load and unload cargo in less than XX minutes.	It is necessary for efficient operation and avoiding excess fuel boil-off to keep the time for load/unload to a minimum
0.6-0.2	0.7-0.3	00-026	The H_2O Acquisition Shall Provide XX Liters to the Fuel Infrastructure	Water for Hydrogen extraction.
0.2-0.4	0.3-0.6.4	00-027	The Fuel Infrastructure Shall meet the fuel demands of the flight schedule.	The Fuel infrastructure must produce enough fuel, or have enough stored to allow the aircraft to fly out on schedule.

Table 3: Level 0 Interface Requirements

2. CHAPTER 2: SUB-SYSTEM OVERVIEW LEVEL 1

2.1. Objective statement

To create a flying platform for Cargo transportation to reduce emissions.

The object of this system is to fulfill the flying cargo function in the level 0 system. The Cargo must be transported from city to city. A major objective of this system is to be green. To do that the Flight system must be fuel efficient and reduce emissions by running on clean fuel.

2.2. OV-1

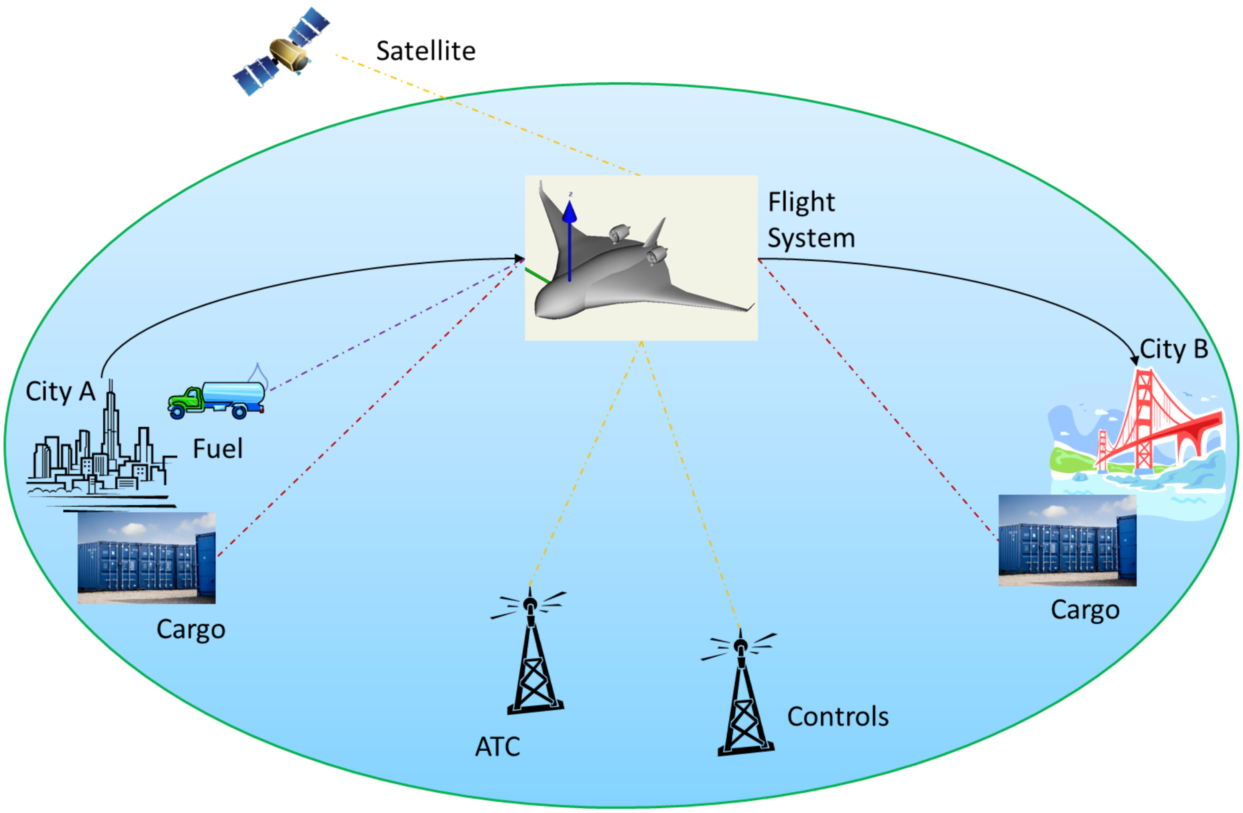

Figure 15: Flight System OV-1

The Flight System OV-1 shows the operation of the Flight System from city to city. The aircraft is connected via data link to communication a navigation systems both on the ground and via satellite. The aircraft is depicted as traveling from one city to the next and is connected to cargo storage and fuel systems at those cities.

2.3. Description

This system will be capable of manned and unmanned operation. When manned the system will be able to be piloted and remotely piloted from the ground control station. The system will be capable of takeoff and landing on standard tarmac runways. During takeoff and landing the Aircraft will be able to run autonomously for unmanned flight and have auto-land and auto-takeoff routine for piloted and remote piloted flight. The system will be capable of varying altitude, heading, velocity, pitch, yaw, and roll with flight control surfaces. These control surfaces can be controlled by the pilot or the autopilot autonomously. The cargo will be loaded in, and placed by automated sequence, but will still allow for human support to control and check the loading process. The Aircraft will be running on hydrogen fuel, and will have and atmospheric bleed valve in case the tank pressure becomes too high. The aircraft will be able to automatically counter wind disturbances to alleviate the work load on the pilot for manned flight.

The Air vehicle involves the use of an aircraft to lift cargo and fly it to its destination. The air vehicle will use recent technology to increase automation and efficiency. Automated cargo loading and unloading, autonomous routines controlling flight, and active aerodynamic flow control are examples of technologies that would benefit the system. The air vehicle will have a modern lightweight structure to increase efficiency, utilizing composite materials. The flight system will have propulsion systems to allow forward motion, and have redundancy to provide reliability. The Air vehicle will communicate with the ground station for control and information. The Air vehicle will be optionally piloted to reduced pilot labor but allow for human transport, redundancy, and security. The flight vehicle will utilize the renewable fuels produced by the Fuel Infrastructure to reduce the dependence on fossil fuels and carbon energy. The air vehicle includes space for cargo, fuel, electronics, and crew.

The Flight System is synonymous to air vehicle, flight vehicle, or airplane. The Flight system just refers to the flying platform. The Air vehicle includes the fleet of aircraft, and all internal systems. The Air vehicle does not include the satellites or ground antennas used for communications. The air vehicle does not include the support systems at the airport. These would include fuel pumps, cargo loaders, personnel, and maintenance equipment as aspect not covered in this system. The Air vehicle does not include to ground station that controls the aircraft during unpiloted flight. That system is part of the level 1 Controls/Compliance System

Inputs to the Air vehicle are generally from ground support. Fuel is an input to the Air vehicle that comes from the level 1 Fuel Infrastructure as the aircraft is fueled up. Cargo is an input to the Air vehicle from the Level 1 Cargo System. Maintenance, repairs and deicing are inputs from the Ground Support. Communications and navigation signal are inputs from Controls/Compliance System. This could come from ground communication and from satellites as well. Air for the engines and ECS is an input from the atmosphere. Undesirable inputs for the air vehicles are also present. Air turbulence and undesired acceleration are undesirable. Radio and other electrical interferences are undesirable. Hacking and GPS spoofing are undesirable inputs.

Outputs include excess fuel that will be drained for storage when the aircraft is not in use. Telemetry data and communication to the ground station are outputs. Cargo is an output when it is unloaded and cataloged for export.

Undesired outputs are also present. Damage and wear to runways are undesired outputs. Potential damage to property in the rare event of a crash is another undesired output. Noise from the operation of turbine engines is another undesired output. The Air Vehicle also outputs NO_x as a result of the heat in the engine operation.

The main product for the Air vehicle is transport from point to point. This transport of materials and personnel is the product that this system is designed to optimize on. Water is another product of the system that is released into the atmosphere as a result of hydrogen burning.

Potential Byproducts for the Air vehicle include NO_x as a result of high temperatures in the engine combustion process. Other byproducts include contrails, which is an unfavorable formation of water, and heat.

2.4. CONOPS

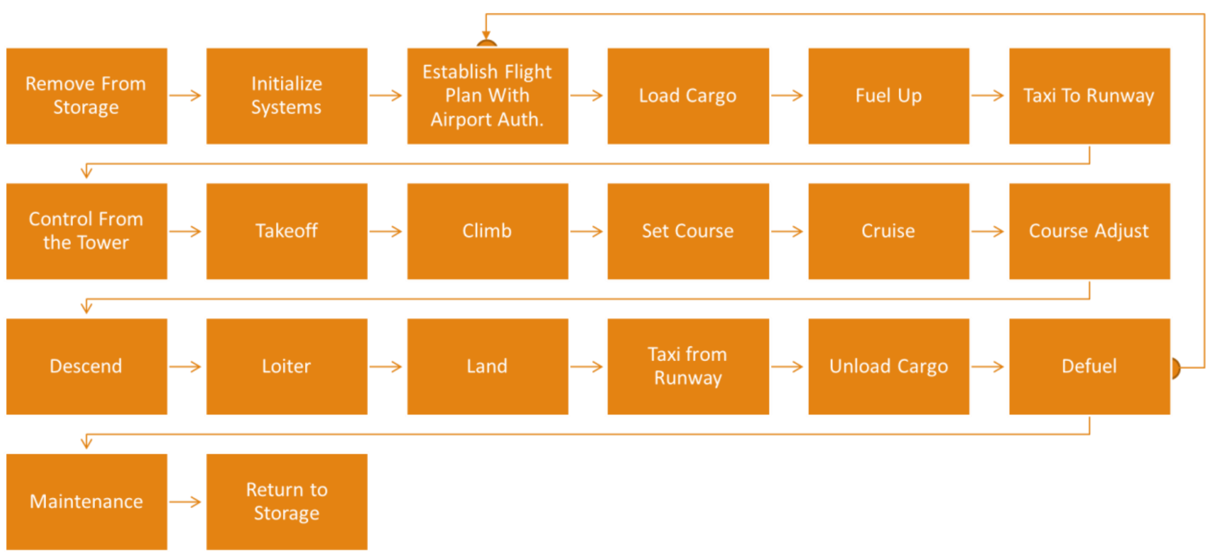

Figure 16: Flight System CONOPS

The concept of operations of the Flight Systems and the associated systems involved are depicted above. The Flight system interfaces with many of the other systems during the operation. The Aircraft is removed from storage, initialized, loaded with fuel and cargo. The Aircraft then takes off and is flown to the destination landing location. After landing the plane is unloaded and either prepared for the next mission or prepared for storage.

2.4.1. Functional sequence diagrams

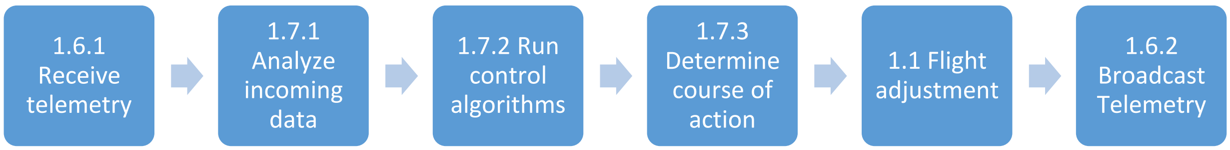

Figure 17: Automated Navigational Correction Sequence

This diagram shows the functional flows of an automated response to flight error or turbulence. This is and automated response to continue the vehicle on the prescribed path when undesirable inputs would otherwise disturb the path. The aircraft receives the navigation telemetry and passes that data to the computers. The computers analyze the incoming data and convert it into a usable format if necessary. The data is then passed to the control algorithms which run the data and determine the error. This information is passed to the controller that determines the correct course of action to rectify the error and a flight adjustment is made. The new telemetry is then broad cast back out to the GPS satellites and ground station.

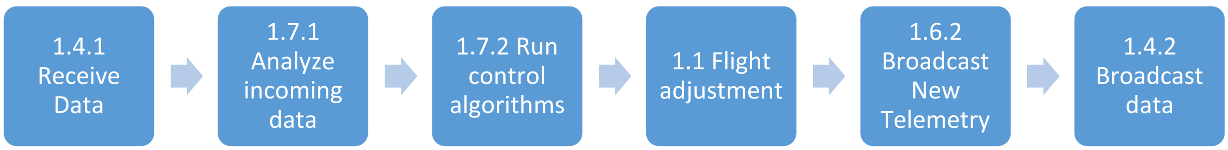

Figure 18: Ground Controlled Course Adjustment Sequence.

This diagram shows the functional flow of a ground controlled course adjustment. The process is similar to the automated navigation. The data is received through the communications equipment and analyzed by the computer programs. The flight is then adjusted according to the instructions from the data instead of from an automated system. The flight is adjusted, and the new flight telemetry is broadcasted as well as confirmation data for the ground crew.

2.5. Functional breakdown

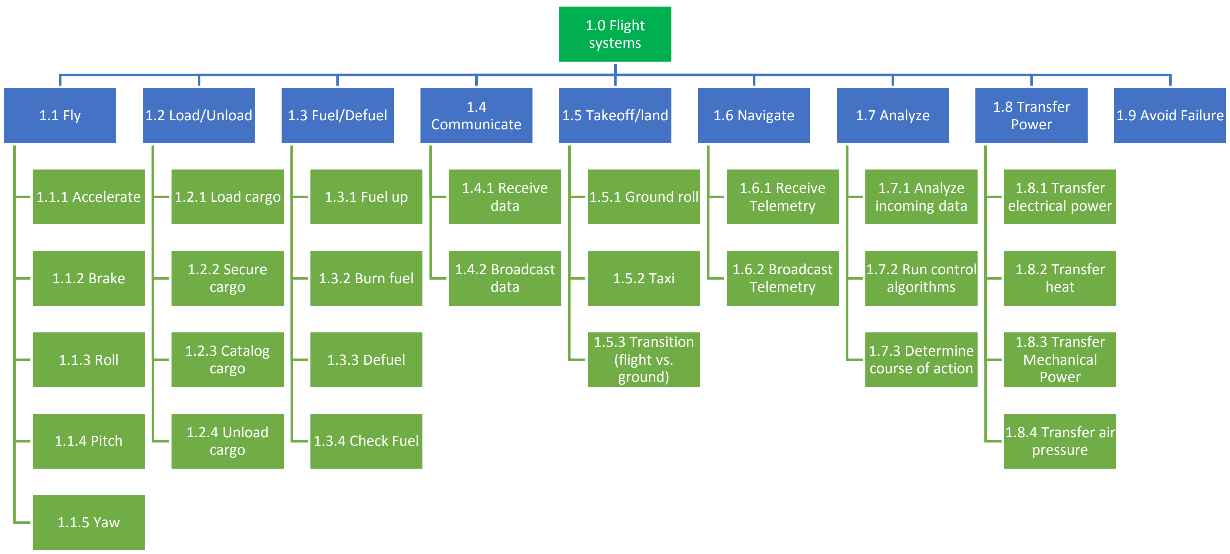

Figure 19: Flight System Functional Breakdown

1.1.Fly:

The process of actually creating lift and controlling the aircraft through the air to the destination. This includes all the standard flight function such as accelerating, braking, banking, pitching and yawing. Climbing, descending would result from a combination of accelerate/braking and pitch. These allow for motion in three dimensions

1.2.Load/Unload

Loading and unloading the aircraft involve putting the cargo in the aircraft. Securing the cargo so it does not move will be necessary as a part of preparing the cargo. The system will likely use pallets or standard containers and these are prepared ahead of time by the Level 1 Cargo System. Cataloging what is on the aircraft and where may be done prior to loading. In that case the data would simply be transferred to the aircraft. Taking the cargo off the plane when it lands is the final step.

1.3.Fuel/Defuel

Fueling and defueling involve putting the fuel in the aircraft, burning it while flying and removing excess fuel after landing. During flight and especially afterward the fuel level (amount) will be checked.

1.4.Communicate

Communicate is a very important function for unmanned flight. Communicate involve the upload and download of electronic information of the aircraft. This includes receiving data, and broadcasting data. Telemetry data is specified for navigational use in the (1.6) Navigate function.

1.5.Takeoff/Land

Although somewhat a subset of flying this function is important enough in the System to get its own function. Takeoff/landing involves the ground roll for takeoff and landing and the associated transition to climb phase, and transition from approach phase (flare). It also includes the taxi to and from the runway.

1.6.Navigate

Navigate is similar to the communicate function but is specified for telemetry use. The telemetry must be received and broadcast out. Navigate is kept separate because of the different functional flows they are involved in and the different external entities they interface with. For example the Navigate function uses GPS data from specific (GPS) satellites.

1.7.Analyze

Analyze covers the computer algorithms as well as pilot decisions. This function includes the analysis of incoming data, running control algorithms for flight, and determining the course of action.

2.6. Product structure

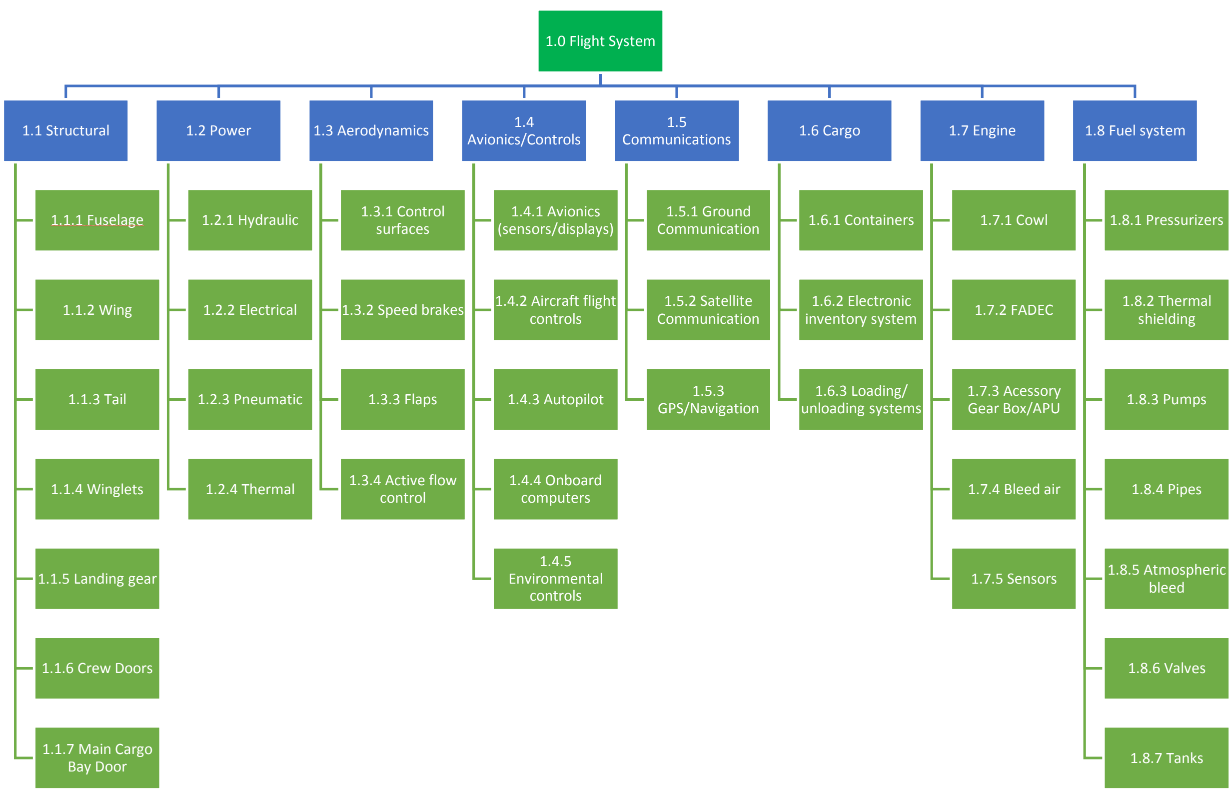

Figure 20: Flight System Product Structure

1.1.Structure

The structural sub-system is responsible for hold the plane together and taking the aerodynamic loads of flying and transfer those loads to keep the plane flying. The structural system includes the aircraft components such as the fuselage, wing, and tail. The fuselage then uses longerons, stringers, and skin to hold its structure. The wing and tail use spars, ribs, and skin as major components making up the structure. In a Hybrid wing body design or all wing design the fuselage and tail components are somewhat missing or are blended into the wing structure. Another important part of the structural system is the landing gear that allows the aircraft to be on the ground for takeoff, landing and taxi. The landing gear also absorbs the load from the transition to flight and back.

1.2.Power

The Power system is the system responsible for the power needs of the entire aircraft when in flight. The power system is composed of four major sub-systems. Hydraulic power is used for the control of the major flight control surfaces as well as the landing gear deployment. Electrical power feeds the communication, navigation and all the computer systems. The electrical system also feeds the secondary flight control surfaces such as the flaps. It is also possible that the electrical system could be used to power pumps and compressor for the pneumatic and hydraulic systems, and be used as a heat source for the thermal system. In this aircraft, the electrical system will be running the systems mentioned as the state of the industry is moving towards all-electric aircraft. The pneumatic system includes all air moving systems such as de-icing and ECS air supply. Lastly, the thermal system is responsible for moving the heat from where it is not needed to where it is. This includes heating and cooling of the sub-systems in the aircraft. For this aircraft the thermal system will use ram air and bleed air from the engine. Thermal heat exchangers and fans will be powered by the electrical system. The figure below shows the power flow from the engine to the power systems.

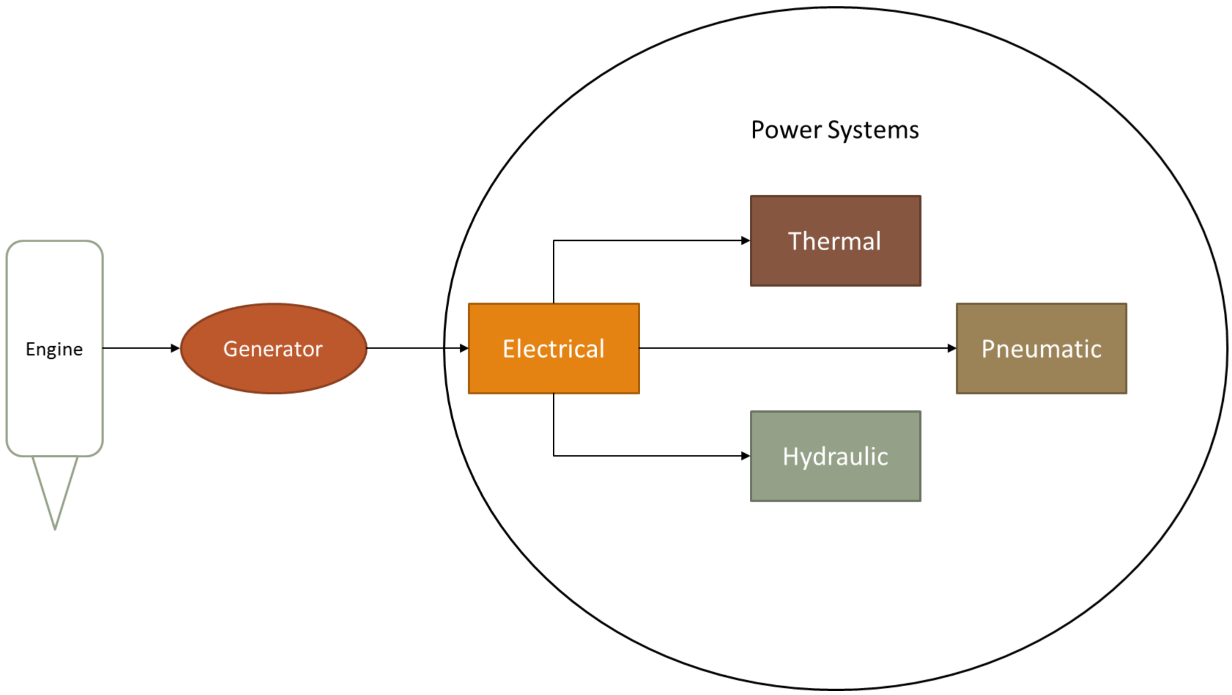

Figure 21: Flight System Power flow Diagram

1.3.Aerodynamics

The aerodynamics sub-system includes aerodynamic devices needed to fulfill the fly functionality. These devices include major flight control surfaces such as: ailerons, elevators, and rudders. It also includes the secondary flight control surfaces like the flaps and speed brakes. Any active flow control, boundary layer devices, or vortex generators would also fall in this sub-system. This design is a Hybrid Wing Body Design. The wing section will include flaps, slats and ailerons. The fuselage section include the elevators at the rear and a vertical stabilizer with a rudder. The airfoil will be cambered on the wings and blended into a more symmetric airfoil for the center fuselage section.

1.4.Avionics and Controls

Avionics and controls is a broad category that includes the aircrafts electronics. The avionics package with its sensors and probes would be included. Flight control computers and autopilot are part of the avionics and controls sub-system. These component are important for keeping the aircraft stable, controllable and steady during flight. They are an important system in fulfilling the unmanned requirement. Controls for the of the ECS system of the aircraft also fall under this sub-system. The avionics will include auto land and auto take off routines. Sensors for flight data such as airspeed and altitude will be included. Subroutines for automatically controlling the aircraft against turbulence will be on the vehicle. Multiple redundant onboard computers that take data and process it outputting control commands and feedback are also important on the vehicle.

1.5.Communications

Communications is a sub-system which is designed for receiving and broadcasting data. The data can be broken into two categories: communications data, and navigation data. Communications data is for ground control, pilot communication, and diagnostic data. The navigational data is for location heading and all other telemetry data for the autopilot, pilot, ground station, and satellites. Navigation will use GPS as a primary source of navigation but will also include inertial navigation systems to be filtered by the GPS data to account for error over time. Communications system will use ground stations and satellites to keep a continuous data link for unpiloted operation. This data link will provide control commands from the ground as well as continuously sending flight data back to the ground control.

1.6.Cargo

Cargo sub-system is a system for the loading, unloading, cataloging, and securing of cargo. The containers and the associated fasteners are used to keep the cargo stationary during flight. The electronic cataloging system is for data and package tracking from the ground. Specialized loading and unloading systems may also be included to interface with the level 1 Cargo System for rapid loading and unloading of cargo. Electrically operated winches along the floor will pull the cargo to the correct locations and secure them. RFID tags will allow for the containers to be accounted for and provide data to the main control computers regarding the intended destination and condition of the container (in case of any excess heat or humidity). Cargo systems

1.7.Engine

The engine sub-system includes the engine and all engine interface systems. The cowl reduces aerodynamic drag for the engine. Generators and bleed air supply the power system with the power they need to operate. FADEC and other sensors interface with the avionics and controls, and also the level 1 Ground Support System. This system will use the CFM International LEAP Engines rated between 25000-30000 lbs of thrust [11]. The engine would need modification to run with hydrogen fuel in an efficient manner. In may be that CFM engine are installed with minimum modification, and later in the maturation of the system new engine are designed from the bottom up to optimized on hydrogen usage.

1.8.Fuel System

For this aircraft the fuel system is of more importance than the fossil fuel burning counterparts. The burning of different kinds of fuel creates a need for a new look at the fuel system. In this case the usage of cryogenic hydrogen fuel increases the complexity and importance of the fuel system. This system includes pressurizers for the tanks, pumps, pipes, and valves. Also important to the cryogenic hydrogen design is a system for atmospheric bleed when the plane is sitting on the tarmac. To minimize this bleed, thermal shielding system will also be in place.

2.7. Diagrams

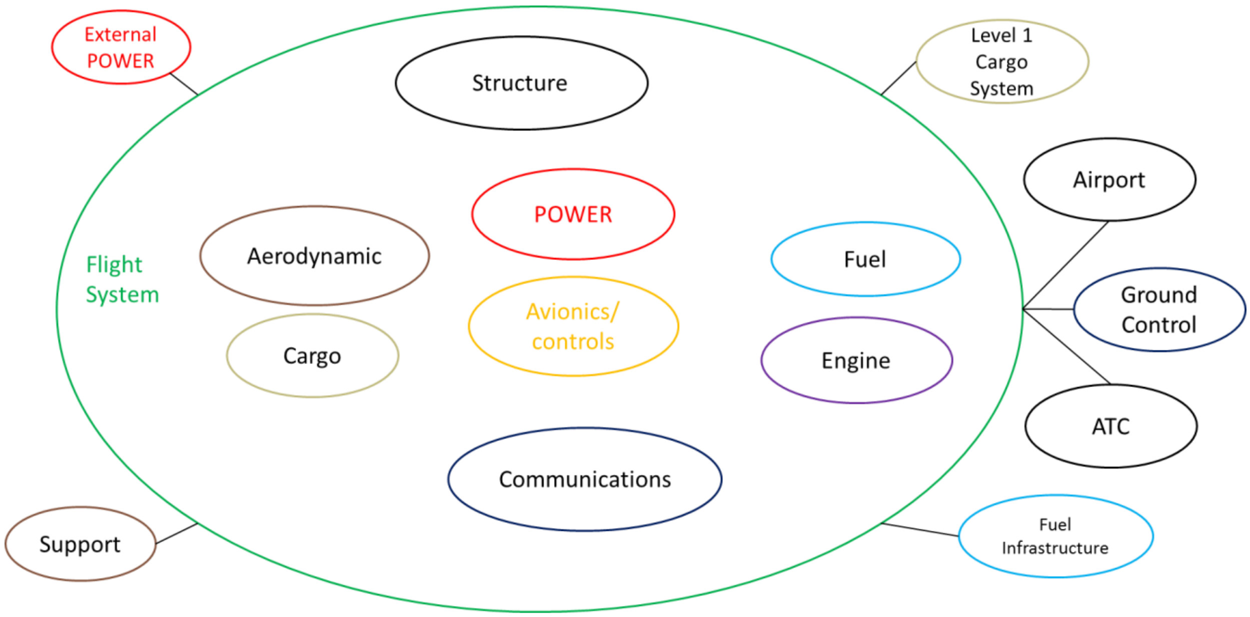

Figure 22: Flight System Context diagram

The above diagram is the context diagram for the level 1 Flight System. The diagram shows relationships between the different sub-systems and the system boundaries of the Flight System and the subsystems. The diagram shows other systems and inputs that are outside the system. All of the sub-systems interface with the structure at some point, if just to be physical secured. For that reason the structure is represented in black enveloping all the other systems.

2.8. Interfaces

	1.1 STRUCTURAL	1.1.1 Fuselage	1.1.2 Wing	1.1.3 Tail	1.1.4 Winglets	1.1.5 Landing Gear	1.1.6 Crew Doors	1.1.7 Main Cargo Bay Door	1.2 POWER	1.2.1 Hydraulic	1.2.2 Electrical	1.2.3 Pneumatic	1.2.4 Thermal	1.3 AERODYNAMICS	1.3.1 Control Surfaces	1.3.2 Speed Brakes	1.3.3 Flaps	1.3.4 Active Flow Control	1.4 AVIONICS/CONTROLS	1.4.1 Avionics	1.4.2 Aircraft Flight Controls	1.4.3 Autopilot	1.4.4 Onboard Computers	1.4.5 Environmental Controls	1.5 COMMUNICATIONS	1.5.1 Ground Communication	1.5.2 Satellite Communication	1.5.3 GPS/Navigation	1.6 CARGO	1.6.1 Containers	1.6.2 Electronic Inventory System	1.6.3 Loading/unloading Systems	1.7 ENGINE	1.7.1 Cowl	1.7.2 FADEC	1.7.3 Accessory gear box	1.7.4 Bleed Air	1.7.5 Sensors	1.8 FUEL SYSTEM	1.8.1 Pressurizers	1.8.2 Thermal Shielding	1.8.3 Pumps	1.8.4 Pipes	1.8.5 Atmospheric Bleed	1.8.6 Valves	1.8.7 Tanks
1.1 STRUCTURAL									X					X					X						X				X				X						X							
1.1.1 Fuselage			x	x		x	x	x		x	x	x	x					x		x	x	x	x	x		x	x	x		x	x	x		x	x	x	x	x		x	x	x	x	x	x	x
1.1.2 Wing					x	x				x	x	x	x		x	x	x	x																									x			x
1.1.3 Tail										x	x	x	x		x			x																												
1.1.4 Winglets																																														
1.1.5 Landing Gear										x			x							x	x																									
1.1.6 Crew Doors											x									x			x																							
1.1.7 Main Cargo Bay Door											x									x			x							x		x														
1.2 POWER														X					X						X				X				X						X							
1.2.1 Hydraulic											x				x	x				x	x	x	x									x														
1.2.2 Electrical												x	x				x			x	x	x	x			x	x	x			x	x			x	x		x		x		x			x	
1.2.3 Pneumatic													x					x		x	x	x	x	x										x			x				x			x		
1.2.4 Thermal																				x			x	x		x	x	x		x				x			x				x					
1.3 AERODYNAMICS																			X														X													
1.3.1 Control Surfaces																		x		x	x	x	x																							
1.3.2 Speed Brakes																				x	x	x	x																							
1.3.3 Flaps																				x	x	x	x																							
1.3.4 Active Flow Control																				x	x	x	x																					x		
1.4 AVIONICS/CONTROLS																									X				X				X						X							
1.4.1 Avionics																					x	x	x	x		x	x	x			x				x			x		x		x			x	
1.4.2 Aircraft Flight Controls																						x	x												x											
1.4.3 Autopilot																							x												x											
1.4.4 Onboard Computers																								x		x	x	x			x				x			x		x		x			x	
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1.6.2 Electronic Inventory System																																														
1.6.3 Loading/unloading Systems																																														
1.7 ENGINE																																							X							
1.7.1 Cowl																																									x		x			
1.7.2 FADEC																																				x	x	x		x		x		x	x	
1.7.3 Accessory gear box																																										x				
1.7.4 Bleed Air																																														
1.7.5 Sensors																																								x		x				
1.8 FUEL SYSTEM																																														
1.8.1 Pressurizers																																											x	x	x	x
1.8.2 Thermal Shielding																																											x			x
1.8.3 Pumps																																											x			x
1.8.4 Pipes																																													x	x
1.8.5 Atmospheric Bleed																																													x	
1.8.6 Valves																																														x
1.8.7 Tanks																																														

Figure 23: Flight System interface diagram

The full interface chart is show above. Less wide spread systems such as the engine system are interfaced to fewer systems, but can be interfaced indirectly. In the case of the engine system it powers the power system which in turn powers all other systems. The power system interfaces with all other system to give them the power to operate. This power can show up in a number of forms (electrical, mechanical, thermal) and allows each other sub-system to function. The power sub-system receives its power from the engine sub-system. The avionics and controls is another sub-system that spans many other systems. As the power sub-system provides the energy to each system, the avionic and controls sub-system provide the control for operation. Engine sub-systems and fuel sub-systems interface to provide the fuel to the engine. Cargo and communication overlap so that the cargo manifest can be communicated to the ground.

2.9. N2 diagrams

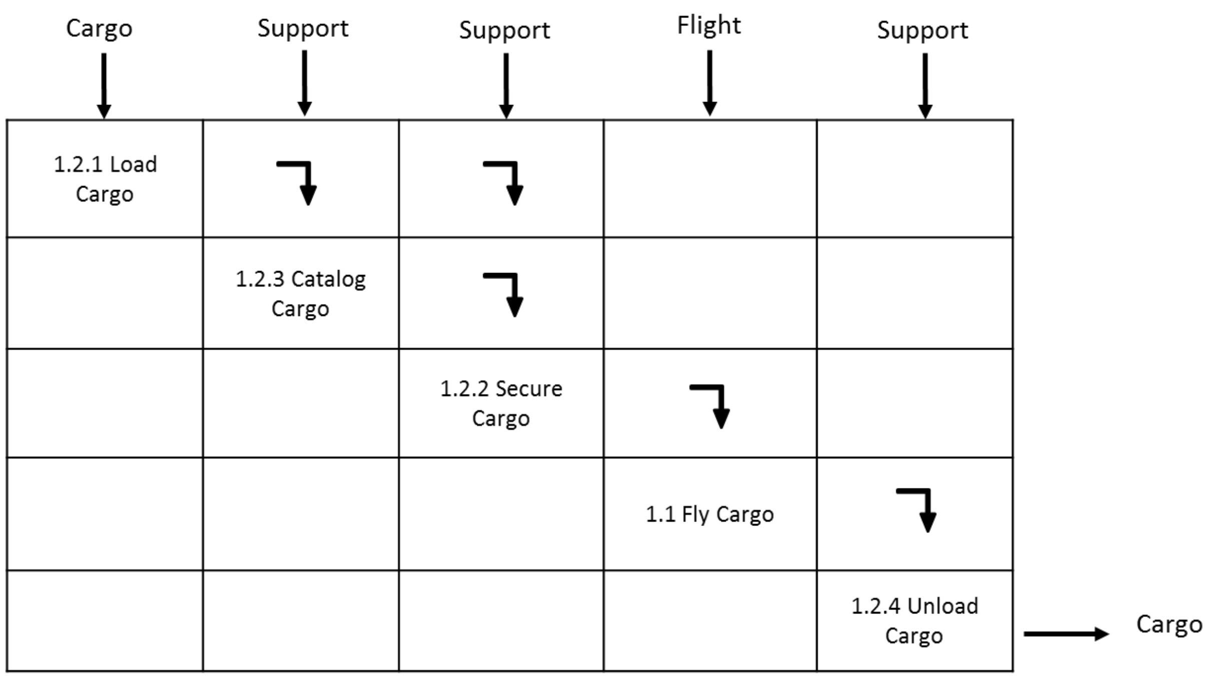

Figure 24: Flight System Cargo N2 diagram

The N2 diagram above shows the process of cargo being loaded, flown and unloaded. The cargo enters as an input and is loaded in the aircraft. The loaded cargo is then and input for cataloging and securing the cargo. Information from the cataloging process may determine location of the containers and is an input to the securing process as a safe guard against securing the cargo in an incorrect location. Inputs of support from off board computers and personnel come in for steps 2, 3, and 5.   The cargo is then flown to the destination and unloaded. Cargo to the Level 1 Cargo System is then the output of the process.

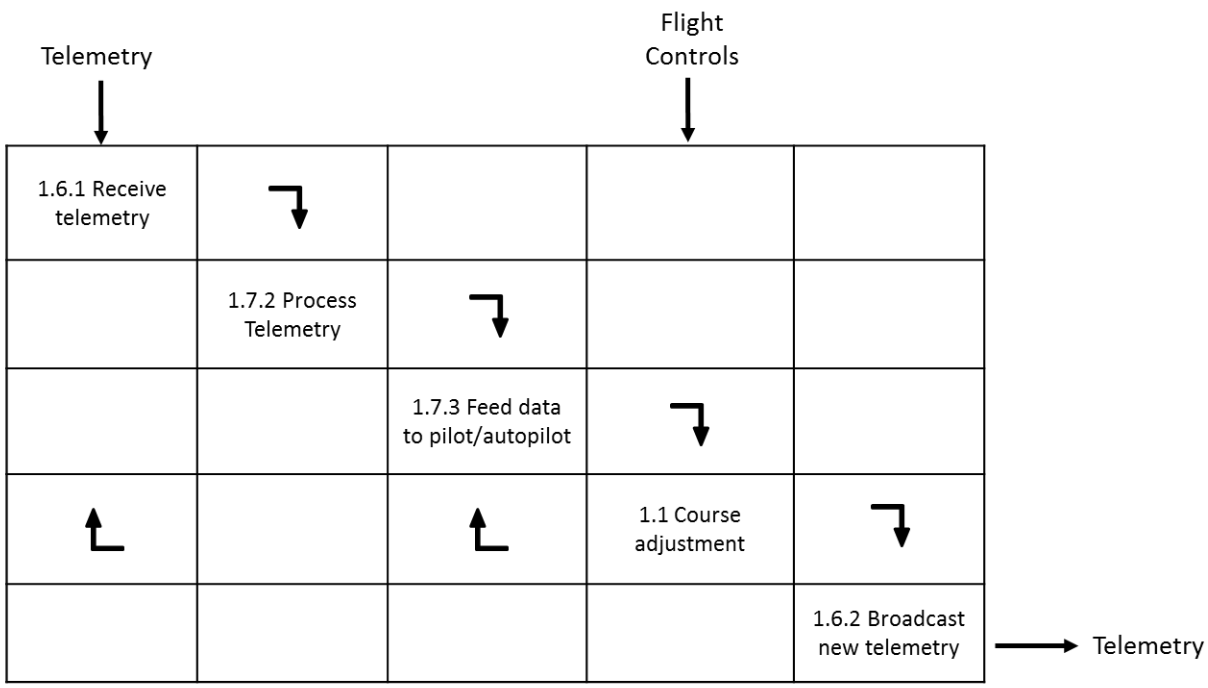

Figure 25: Flight System GPS/Control N2 diagram

GPS telemetry and Control processes are shown in the diagram above. Telemetry in received as an input in the first step. The telemetry is processed and sent to either the pilot via display or to the autopilot software. The course of the aircraft is adjusted and as the adjustment occurs there is a feedback to the telemetry being constantly received. This feedback loop ensures the corrective action is giving its intended result. Feedback is also provided to the pilot/autopilot to communicate the changes in the aircraft. After the pilot/autopilot effects a course adjustment, the new telemetry is broadcast out as an output.

2.10. Top Level Requirements

Product	Function	Req. No	Requirement	Rationale
1.8	1.3.2	04-001	The Flight System Shall use Hydrogen as the source of fuel	This allows green operation
1.4	1.6.3	04-002	The Flight System Shall be Capable of remote piloted Flight	This will help allow the manned labor to be reduced. It also reduces pilot loss of life.
1.4.2	1.6.3	04-003	The Flight System Shall be Capable of Piloted Flight	This allows ferrying of personnel, and allows pilots to monitor the unmanned systems for redundancy and verification.
1.4.3	1.6.3	04-004	The Flight System Shall be Capable of Autonomous Flight	This will further reduce manned labor, increase efficiency, and it also reduces pilot error.
1.0	1.3.2	04-005	The Flight System Shall make use of new technologies to improve fuel efficiency.	Fuel efficiency and minimizing emissions is a key goal of this system.
1.4	1.6.3	04-006	The Flight System Shall make use of redundancy in the control of the aircraft to increase safety	The public image of this system is a major threat to the system being implemented. This will allow the aircraft to have an autopilot routine in the case of data link or pilot control loss.
1.5	1.4	04-007	The Flight System Shall make use of highly secure data links and onboard computers to increase safety	The security of UAVs has been a major concern. This system needs to have secure data links and computers.
1.0	1.1	04-007	The Flight System maintenance Shall be "on condition" rather than scheduled.	This will allow for maintenance only when it is needed as opposed to regular intervals.

Table 4: Level 1 Top Level Requirements

2.11. Sub-system Requirements

Product	Function	Req. No	Requirement	Rationale
1.1	1.1	04-008	The structure Must be compliant with FAA PART 25 [13]	This is a standard that is applied to all aircraft with MTOW greater than 19,000lbs [13]
1.1	1.9	04-009	The structure Shall have a physical location and anchor for each sub-system	This gives all systems a place to go and be secured.
1.2	1.8	04-010	The Power System Shall provide power to all required systems	Allowing the function of the powered systems in the aircraft
1.2	1.8	04-011	The Power System Shall include 2X redundancy to minimize the risk of power loss.	Power loss can mean the loss of an aircraft
1.2.2	1.8.1	04-012	The Power System Shall generate (TBD) kW of electrical power.	Electrical power for the electric systems
1.2.4	1.8.2	04-013	The Power System Shall generate (TBD) MJ of thermal energy to run the ECS system	ECS system keeps the pressure and temperature at a reasonable level for the pilot and cargo.
1.2.3	1.8.4	04-014	The Power System Shall generate (TBD) kg/s of pneumatic flow to run the ECS system	ECS system keeps the pressure and temperature at a reasonable level for the pilot and cargo.
1.2.1	1.8.3	04-015	The Power System Shall provide 3000PSI (~20.5 Mpa) of hydraulic pressure to run the flight control systems through all flight segments	Hydraulics allows the aircraft to be controllable through the flight control surfaces
1.2	1.8	04-016	The Power System Shall weigh less than (TBD) kg for the largest model	Minimizing weight of the aircraft is important to efficiency
1.3.1	1.1	04-017	The Aerodynamics System Shall provide control surfaces to control the flight of the aircraft.	These are required for stability and control
1.3.1	1.1.4	04-018	The Aerodynamics System Shall have elevators capable of providing (TBD) rad/s of pitch rotation rate	This allows an aircraft to maneuver longitudinally.

Table 5: Level 1 Sub-System Requirements

1.3.1	1.1.3	04-019	The Aerodynamics System Shall have Ailerons capable of providing (TBD) rad/s of roll rotation rate	This allows an aircraft to maneuver laterally.
1.3.1	1.1.5	04-020	The Aerodynamics System Shall have a rudder capable of providing (TBD) rad/s of unbanked turn rotation	This allows an aircraft to maneuver directionally.
1.3.1	1.1	04-021	The Aerodynamics System Shall have controls capable of providing (TBD) rad/s of turn rotation rate	This allows an aircraft to turn fast enough to maneuver in and out of formations after takeoff and before landing.
1.3.2	1.1.2	04-022	The Aerodynamics System Shall include air brakes	This allows the aircraft to slow down more quickly
1.3.3	1.1	04-023	The Aerodynamics System Shall include Flaps	This allows greater lift for takeoff and landing.
1.3.3	1.1	04-024	The Flap deployment rate Shall be (TBD) rad/s	This allows flaps to deploy in a timely manner to give the change in lift he expects.
1.4	1.6	04-025	The Avionics/Controls System Shall process data incoming and outgoing	This is the central computer for processing, receiving, and broadcasting data.
1.4.4	1.1	04-026	The Avionics/Controls System Shall have a Flight Control Computer to control the Aero Control surfaces	This allows autopilot and other automatic control functions to control the aircraft
1.4.5	1.6	04-027	The Avionics/Controls System Shall have a Thermal Control Unit to control the ECS system	The Avionics will keep the temperature and pressure at a reasonable level.
1.4.2	1.1	04-028	The Avionics/Controls System Shall provide physical controls for pilots	This allows manned flight.
1.4.2	1.1	04-029	The Avionics/Controls System Shall allow the pilot to override any flight controls	This allows the pilot or remote pilot to take control if the Avionics/Controls System is malfunctioning
1.4.1	1.4.1	04-030	The Avionics/Controls System Shall provide sensors to determine aircraft altitude.	This allows the pilot or automation know the altitude. Situational awareness.
1.4.1	1.4.1	04-031	The Avionics/Controls System Shall provide sensors to determine aircraft airspeed.	This allows the pilot or automation know the airspeed. Situational awareness.
1.4.1	1.4.1	04-032	The Avionics/Controls System Shall provide sensors to determine aircraft attitude.	This allows the pilot or automation know the attitude. Situational awareness.

Table 5 (cont.)

1.4.1	1.4.1	04-033	The Avionics/Controls System Shall provide sensors to determine aircraft heading.	This allows the pilot or automation know the heading. Situational awareness.
1.4.1	1.4.1	04-034	The Avionics/Controls System Shall provide sensors to determine aircraft bank angle.	This allows the pilot or automation know the bank angle. Situational awareness.
1.5.1	1.4	04-035	The Communication System Shall be able to send and receive data to/from the ground	This allows the aircraft to communicate with ground control and ATC.
1.5.2	1.4	04-036	The Communication System Shall be able to send and receive data to/from orbiting satellites (SAT COM)	This allows the aircraft to communicate with satellites for long distance communications.
1.5.3	1.4	04-037	The Communication System Shall be able to send and receive telemetry data to/from orbiting satellites (SAT COM)	This allows the aircraft to determine its location and velocity for navigation.
1.6.1	1.2	04-038	The Cargo System Shall use current Unit Load Devices to hold the cargo	This allows the cargo to be sectioned off which helps with loading and unloading and is helpful for balance. Also using and already produced ULD allows compatibility with current systems
1.6.2	1.2.3	04-039	The Cargo System Shall catalog the size, weight, item, and destination of each package	This will allow for data for cargo transfers and tracking of the packages by the ground crew.
1.6	1.2.2	04-040	The Cargo System Shall provide a means to secure the containers to the aircraft for flight	This prevents the Center of Gravity to shift unexpectedly due to cargo moving around
1.6.3	1.2	04-041	The Cargo System Shall provide a means for loading/unloading cargo in under 15 min.	This will allow for efficient operation of the SOS
1.6	1.2	04-042	The Cargo System Shall automatically load the cargo into position and secure it once it passed through the door	This increases automation and decreases the labor required
1.6	1.2	04-043	The Cargo System Shall locate the cargo such that the aircraft Center of Gravity is XX-YY ft (TBD from airframe) from the front of the aircraft	This prevents instability and ensures controllability and that the A/C is trimmable.

Table 5 (cont.)

1.7	1.1.1	04-044	The Engine System Shall provide thrust to the aircraft	Allowing for flight
1.7.3	1.8.3	04-045	The Engine System Shall provide (TBD) bhp to the accessory gearbox to run the Power System	The engine is the source of the power for the aircraft.
1.7.3	1.8.3	04-046	The Engine System Shall provide an Auxiliary Power Unit that provides (TBD) bhp to run the Power System	This allows the Power System to run when the aircraft is on the ground, or if the engines fail.
1.7.2	1.4	04-047	The Engine System Shall be controlled from an onboard FADEC that interfaces to the Avionics/Controls System	FADECs are common controllers that come with most commercial engines
1.7.5	1.9	04-048	The Engine System Shall have sensors to detect failures or maintenance items	This will allow maintenance to be on condition rather than scheduled.
1.8	1.3.2	04-049	The Fuel System Shall be capable of running on hydrogen	Necessary for hydrogen operations
1.8.2	1.9	04-050	The Fuel System Shall have thermal insulation	This shields both the airframe and the fuel from any thermal effects
1.8.5	1.9	04-051	The Fuel System Shall allow for atmospheric bleed	This is necessary when the plane is not burning enough fuel to relieve tank pressure.
1.8.7	1.9	04-052	The Fuel tanks Shall be capable of holding pressures of 6 bar	This prevents regress of oxygen and allows fuel flow via pressure
1.8.5	1.9	04-053	The Fuel System Shall vent hydrogen gas to the atmosphere at pressures greater than 7 bar	This allows the tanks to remain at safe pressures
1.8.4	1.3.2	04-054	The Fuel System Shall deliver gaseous hydrogen to the engine	This allows the engine to operate

Table 5 (cont.)

2.12. Interface Requirements

Product	Function	Req. No	Requirement	Rationale
1.1-1.7	1.9	04-055	The Structure System Shall provide sufficient strength to hold the engine at maximum acceleration plus 50% safety factor	The engine mounts are some of the highest structural load areas
1.1-1.3	1.9	04-056	The Structure System Shall not allow any aero-elastic divergence during flight	Aero-elastic divergence happens at too high a dynamic pressure and causes loss of aircraft
1.1-1.3	1.9	04-057	The Structure System Shall not allow any aero-elastic Limit cycle flutter during flight	Aero-elastic limit cycle flutter causes damage and fatigue to the airframe and under some circumstances can cause loss of aircraft
1.3-1.7	1.1.1	04-058	The Aerodynamics System shall not interfere with the engine system	Aero must not block inlets or thrust jets
1.4.5-1.8	1.3.2	04-059	The Onboard Computer System Shall control the fuel systems operation	Allowing for the necessary fuel to get to the engine
1.4.5-1.7.2	1.6.2-1.1.1	04-060	The Onboard Computer System Shall control the FADEC on the engine	This allows control of engine thrust and operation.
1.5-0.5	1.4	04-061	The Communication System Shall have a secure link between ground stations or satellites	This allows for security of the system
1.6.1-0.3	1.2	04-062	The Cargo System Shall use the same containers as the Level 1 Cargo System	This allows the containers to be transferred on and off the Aircraft and prevents the need to re-containerize.
1.6.3-0.3	1.2-0.5	04-063	The Aircraft Cargo Loading System Shall use equipment compatible with the Level 1 Cargo System equipment	This allows the flight system to be compatible with the Level 1 Cargo system equipment so that the cargo can be transferred easily between the two Systems. (don't want the flight system with a square peg and the Level 1 Cargo system with a round hole)

Table 6: Level 1 Interface Requirements

1.7-1.0	1.9	04-064	The Engine system Shall not cause any damage to other systems during operation	Heat from exhaust and vibrations must not harm the Flight System. Also there should not be any unwanted impingement on flight control surfaces.
1.8-0.2	0.4-1.3	04-065	The Fuel System external port Shall be compatible with the instrumentation used in the Fuel Infrastructure.	This allows fueling and defueling.
1.8-Atm.	1.3.3	04-065	The Fuel System Shall have an external port for atmospheric venting of fuel.	This allows the tanks to remain at safe pressures and some defueling.

Table 6 (cont.)

3. CHAPTER 3: LITERATURE STUDIES

3.1. H_2

The use of hydrogen has studied at times because of its environmentally friendly properties. This study chose hydrogen as the fuel source over other potential fuel to minimize emissions and because it is a renewable resource. Any hydrogen burned during flight with result in water that will end up back in the oceans and lakes.

Hydrogen also has another advantage over other conventional fuel: energy density. The mass energy density for hydrogen is much higher than conventional fuels. This makes hydrogen very attractive for flight as weight is directly related to the fuel efficiency. For this reason, hydrogen is often used in rockets as fuel energy-to-weight is of high concern.

A major drawback, however, is the volumetric energy density is very low. This is because the density of even liquid hydrogen is over ten times less dense than JET-A fuel. For this reason, the tanks to hold the fuel would have to be extremely large. That would cause more parasite drag of the aircraft, and les room for other things like passengers. The hydrogen fuel would either by highly pressurized or cryogenically liquefied. In either one of these scenarios the tank shape would be biased toward cylindrical or spherical. Table 7 shows the comparison between hydrogen and standard fuel.

H2 Vs. JET-A	H2	Jet Fuel
Energy per mass	120 MJ/kg	43.15 MJ/kg
Energy per volume	8.7 MJ/L	34.7 MJ/L
Tank shape restriction	Spherical/cylindrical	N/A

Table 7: Hydrogen Vs. Jet-A

The use of cryogenic hydrogen has been studied by Airbus in 2000 in a study called CRYOPLANE. The study outlined many of the problems and potential benefits of hydrogen fuel. The study used cylindrical tanks to store the hydrogen. The study used an overhead configuration for hydrogen storage as is seen in the figure below.

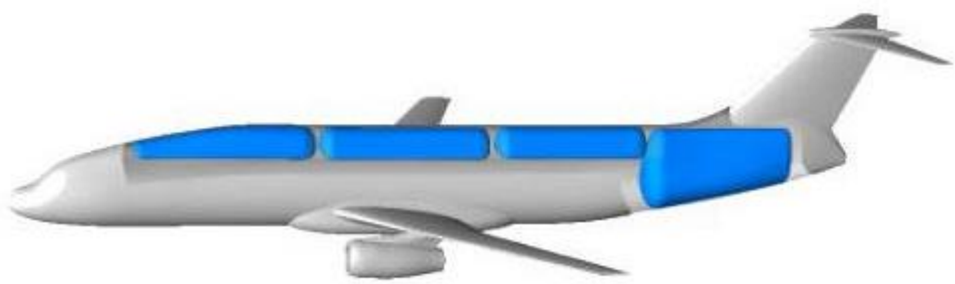

Figure 26: CRYOPLANE Configuration [1]

The study also looked into the usage of a Hybrid wing-body (HWB) design. The HWB design is not naturally a good pressure vessel but it does have a surplus of unused volume. This unused volume is one of the reasons it will be used for this study. Hydrogen tanks are also difficult to fit in the wings the way that conventional fuel tanks can be. This is partially alleviated by the fact that hydrogen is much lighter. The Hybrid wing design is mostly wing and so care must be taken when fitting tanks into the HWB. Below is the figure from the CRYOPLANE study as well as a model creating using AVID PAGE software.

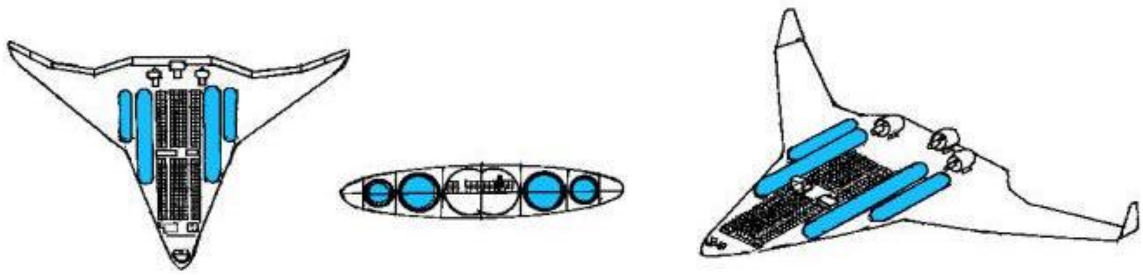

Figure 27: CRYOPLANE HWB Configuration [1]

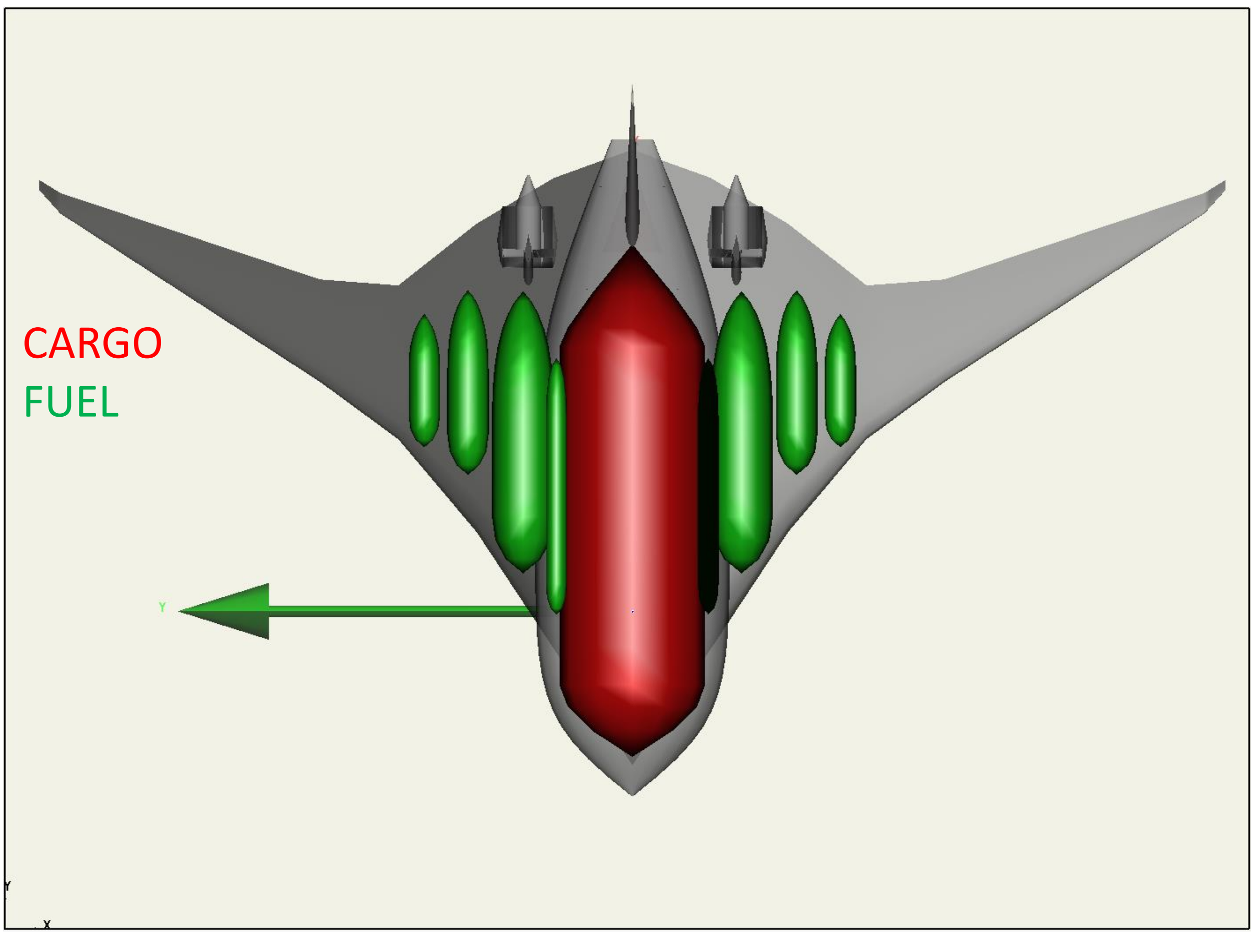

Figure 28: PAGE Generated Configuration

Other than configuration, tank weight is another concern for hydrogen. CRYOPLANE identified that the majority of hydrogen tanks are either too heavy or (as is the case in rocketry) are designed to operate for only a few minutes. Shown below is a graph with six hydrogen tank options. The X-axis is simply the different options 1—6. The Y-axis is the weight of hydrogen as compared to the fuel system weight.

$$H_2\ Weight\ \% = \frac{W_{H_2}}{W_{H_2} + W_{empty}}$$

For example: Space Shuttle External Tank

$$H_2\ Weight\ \% = \frac{226493lbs}{226493lbs + 78100lbs} = 74.36\%$$

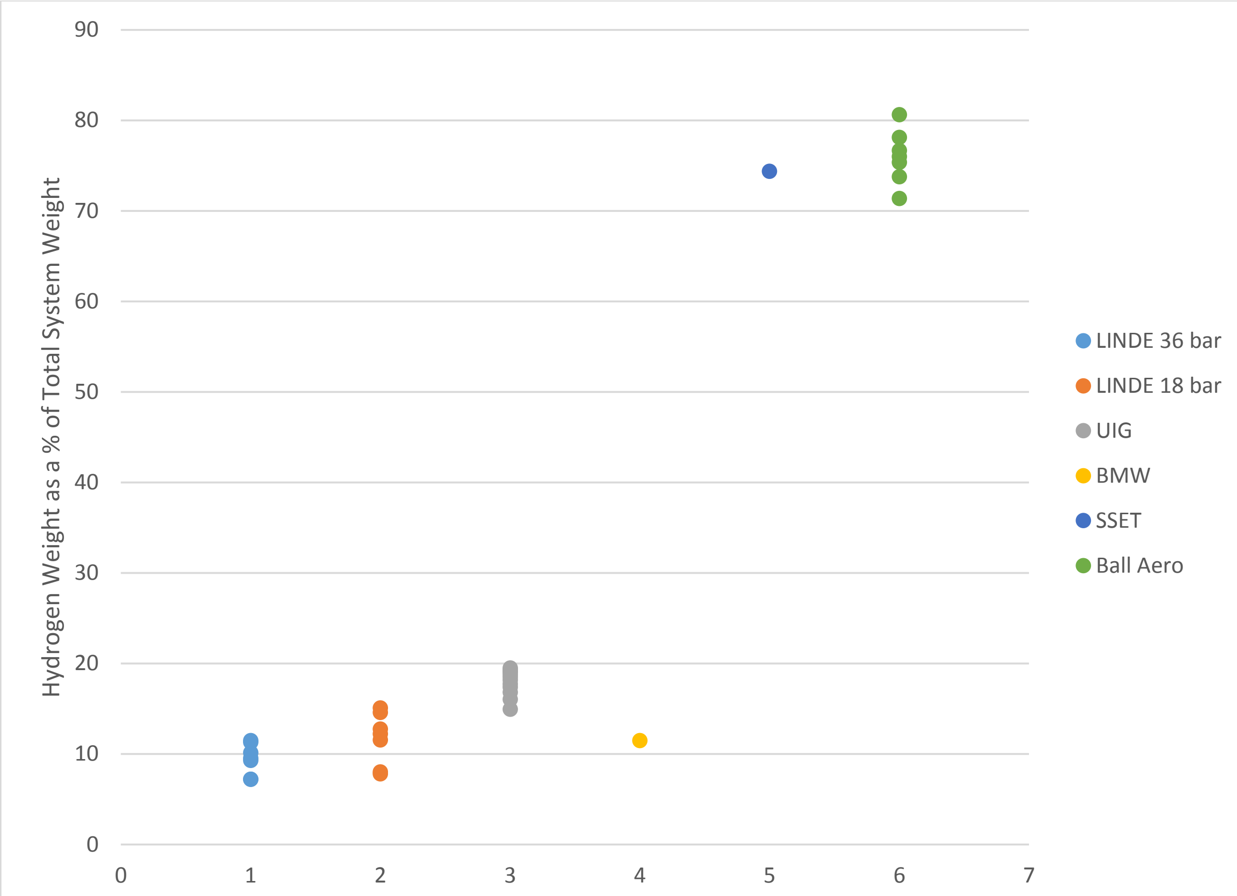

Figure 29: Hydrogen % of Different Tank Systems [2][3][4][5][6]

There are six total systems represented on this chart. The first system is a 36 bar pressurized Linde tank. There are a range of volumes represented the larger to volume the higher the hydrogen weight percentage. This is also the case with the second option: Linde 18 bar pressurized tanks. These tanks achieve slightly higher percentages. UIG tanks are next. These tanks have much higher volumes and have higher percentages. The next system was created by BMW for use in automobiles, these tanks have very small volumes but a reasonable weight percentage compared to the first three (considering how small the volume is). The fifth system is the Space Shuttle External Tank. This tank has a very high percentage (and also carried liquid oxygen). The SSET has the largest volume by far and, with the liquid oxygen taken out of the equation, likely has the best hydrogen weight percentage. Ultimately, however, this system is a one-time use system that is only designed to operate on the order of minutes. The last option is the Ball Aerospace developed hydrogen tanks for the Boeing Phantom Eye. These tanks are designed for long use and also have a very high percentage. They will be the basis for the tanks in this System.

3.2. Cargo volumes

Part of the potential outcomes of this system is that reduction of diesel burning semi-trucks on the road. These trucks contribute to the pollutants released into the atmosphere. If an aircraft is to replace these trucks the cargo volumes and payloads must be investigated to see what an aircraft must be able to handle.

Truck volumes range depending on which trailer is being used. Table 8 describes the different truck options and the associated volumes.

Trailer Type	Internal Cargo Volume (ft^3)
28' High Cube	2029
45' Wedge	3083
48' Wedge	3566
53' Wedge	4050

Table 8: Trailers and Associated Cargo Volumes [7]

The cargo volumes range from 2000-4000ft^3. The aircraft that is being designed should reflect these volumes. In the United States the maximum total weight of a semi-truck and trailer is 80,000lbs. When the truck and cab empty weight are subtracted out you are left with a payload weight between 35,000lbs and 50,000lbs. [8]

3.3. Airport lengths

The airports that can be serviced by this system is of interest. If a town or city has an airfield that is short or unpaved this changes the requirements for any aircraft flying in and out. Airfield data from the state of Illinois is shown below in a histogram format. The airfields shown below are only the paved runways in Illinois.

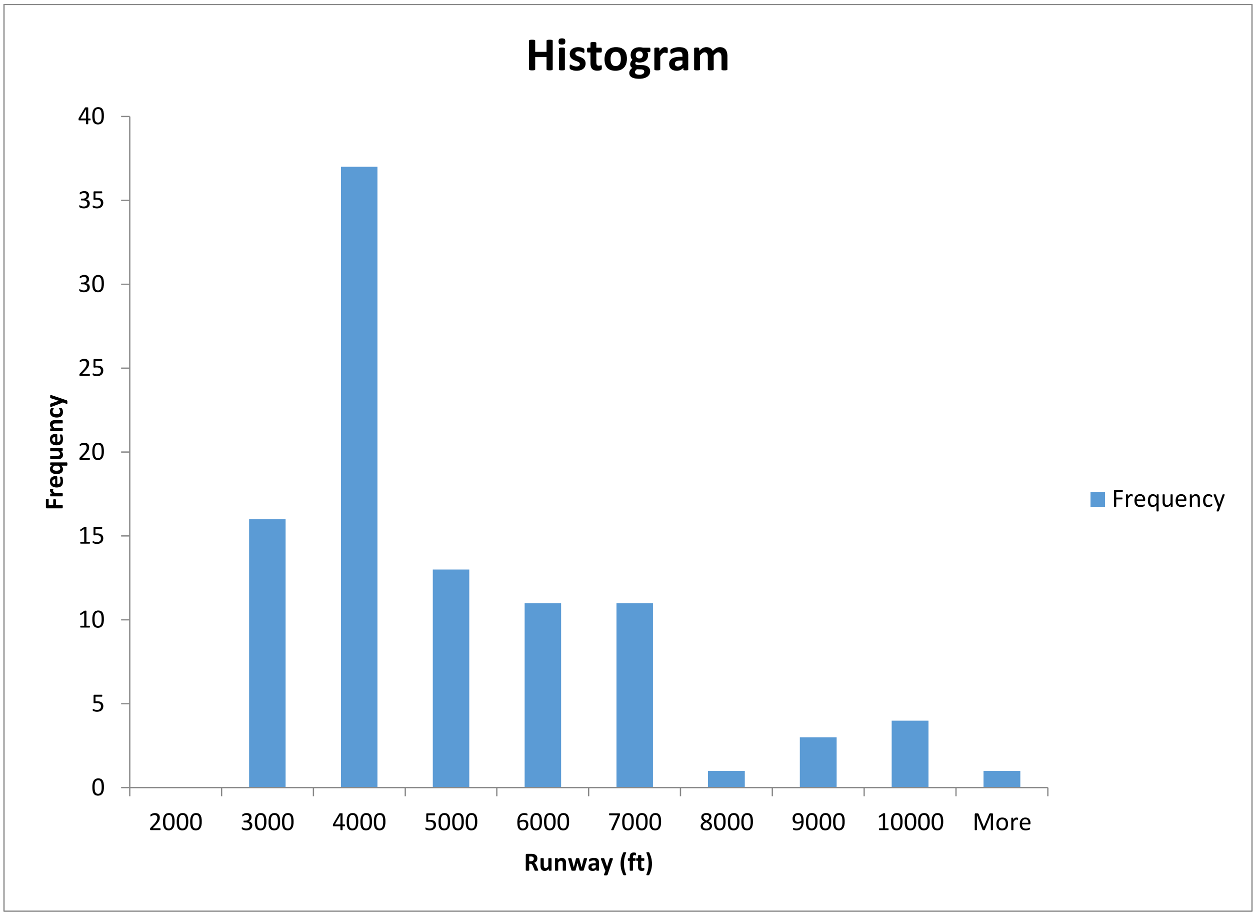

Figure: 30 Airport Runways in Illinois [12]

The figure's bins represents runway lengths from the previous bin up to that bins value. For example, the 3000 value represents runways from 2001 – 3000ft. From this graph we can see that there are many runways from 5001ft and up. These 31 airports would be capable of servicing a medium to large aircraft. Including the runways from 4001ft the number increases to 44 airports. This would correspond to small to medium sized aircraft. Finally, including runways from 3001ft the number of airports would increase to 81. This would be only small aircraft. If 3001ft and up is achieved it will correspond to over 80% of the sample of airports. Assuming the sample is a reasonable sample for the United States this enables the majority of U.S. airports to be serviced by at least one of the aircraft sizes.

4. CHAPTER 4: AIRCRAFT SYNTHESIS (ACS)

4.1. Intro

The ACS tool is a rapid synthesis tool used for generating initial design data. The tool is based on the NASA ACSYNT toolset, and uses FORTRAN code in its execution. The input file is in a text based format that calls individual modules based on “namelists” in the input file. ACS (Aircraft Synthesis) uses simple geometries including fuselage, tail, and wing. [14] The tails and wings can be tapered, swept, twisted, and can have dihedral, but multi-sectional wing geometries are not possible. The thickness to chord ratio is used in the place of airfoils.

4.2. Aircraft Input

To simulate the usage of a Hybrid Wing Body (HWB) the aircraft was input as a large wing, a fuselage and a vertical tail. The engines are attached to the rear of the fuselage. The result of these inputs look like the following:

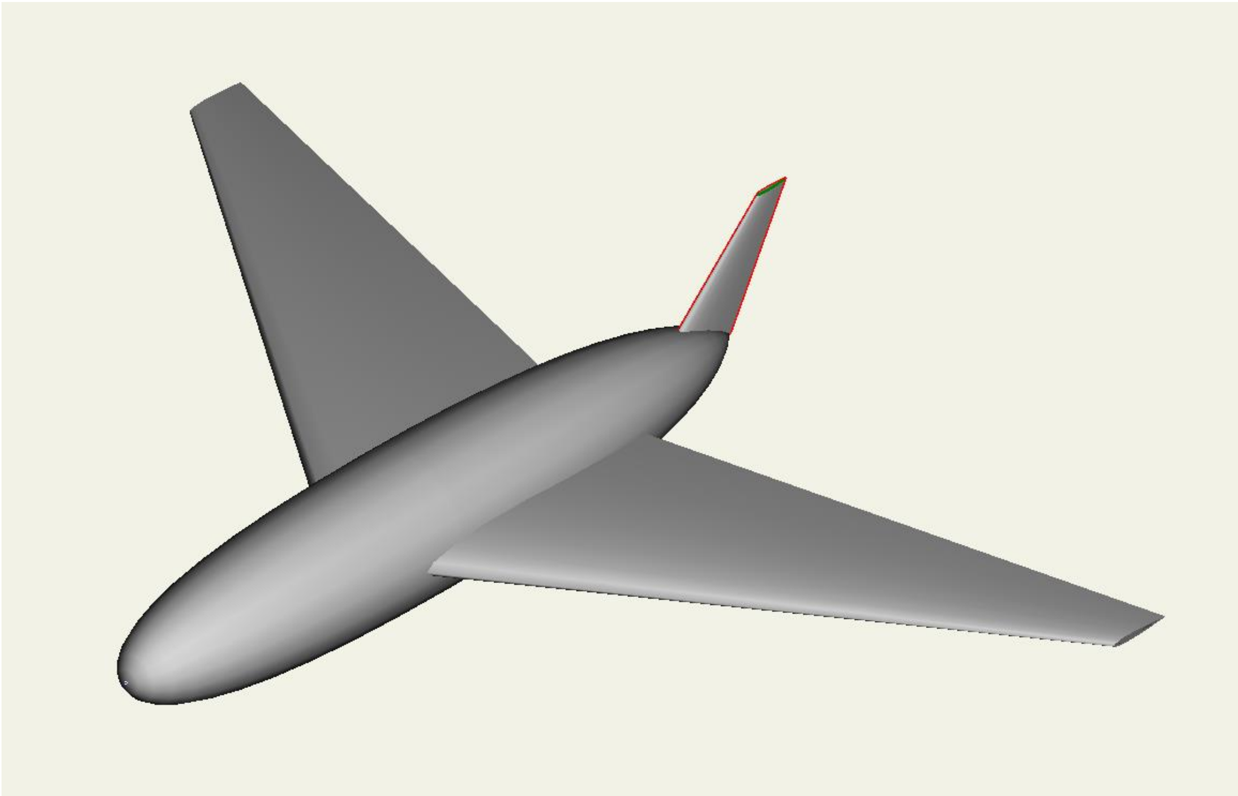

Figure 31: HWB Approximation in ACS

The picture below shows a comparison between a HWB and the ACS approximation. The ACS loses show efficiency in that the fuselage provides little lift and the structure weight is higher as it must hold a higher wing bending moment. An actual HWB would allow for lower structural weight. The ACS program also estimates weight based on the standard in which it was conceived. This means that 787 era composite advances are not taken into account and the program can overestimate the total weight of the aircraft.

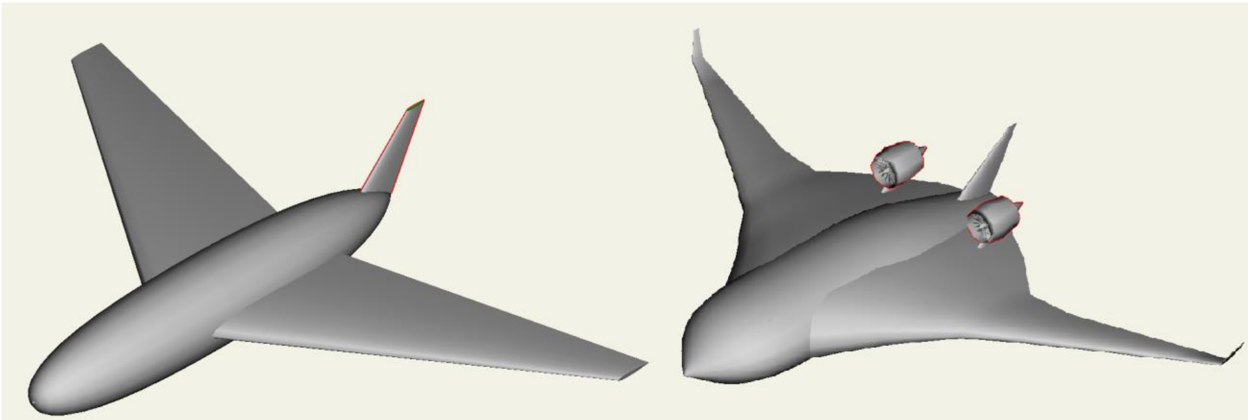

Figure 32: HWB Vs. Approximation in ACS

4.3. Run cases

The first run cases were identical aircraft. These aircraft were run through identical missions and the resulting fuel weight and aircraft weight were extracted for each flight. The only difference in these first run through was the fuel used. Both Aircraft were modeled after the C-130 as a general sizing point. Table 9, summarizing the design variables, is shown below

Variable	ZH-001 (hydrogen)	ZH-002 (Jet Fuel)
Wing area	2500 ft^2	2500 ft^2
Wing AR	6	6
Wing Sweep (1/4 chord)	30°	30°
Wing Taper Ratio	0.2	0.2
Fuselage Length	80 ft	80 ft
Fuselage Max Diameter	15 ft	15 ft
Internal Fuselage Volume	7359 ft^3	7359 ft^3
Design Mission Fuel Volume	3182 ft^3	1083 ft^3
Design Mission Fuel Weight	14075 lbs	54166 lbs
Design fall out Range	4000 nm	4000 nm
MTOW	127591 lbs	175696 lbs
Payload Weight	45000 lbs	45000 lbs

Table 9: Aircraft Characteristics

With these design variable the two aircraft were compared by flying a range of missions of varying payload weights and flight distances. While only symmetric airfoils are considered, ACS allow the user to input a C_{L0} for the wing to compensate. A value of 0.3 was chosen based on manual variance of the variable (large step size) and minimizing the total fuel weight. The following graphs are comparison graphs of the two aircraft, measuring the total aircraft weight and the fuel weight.

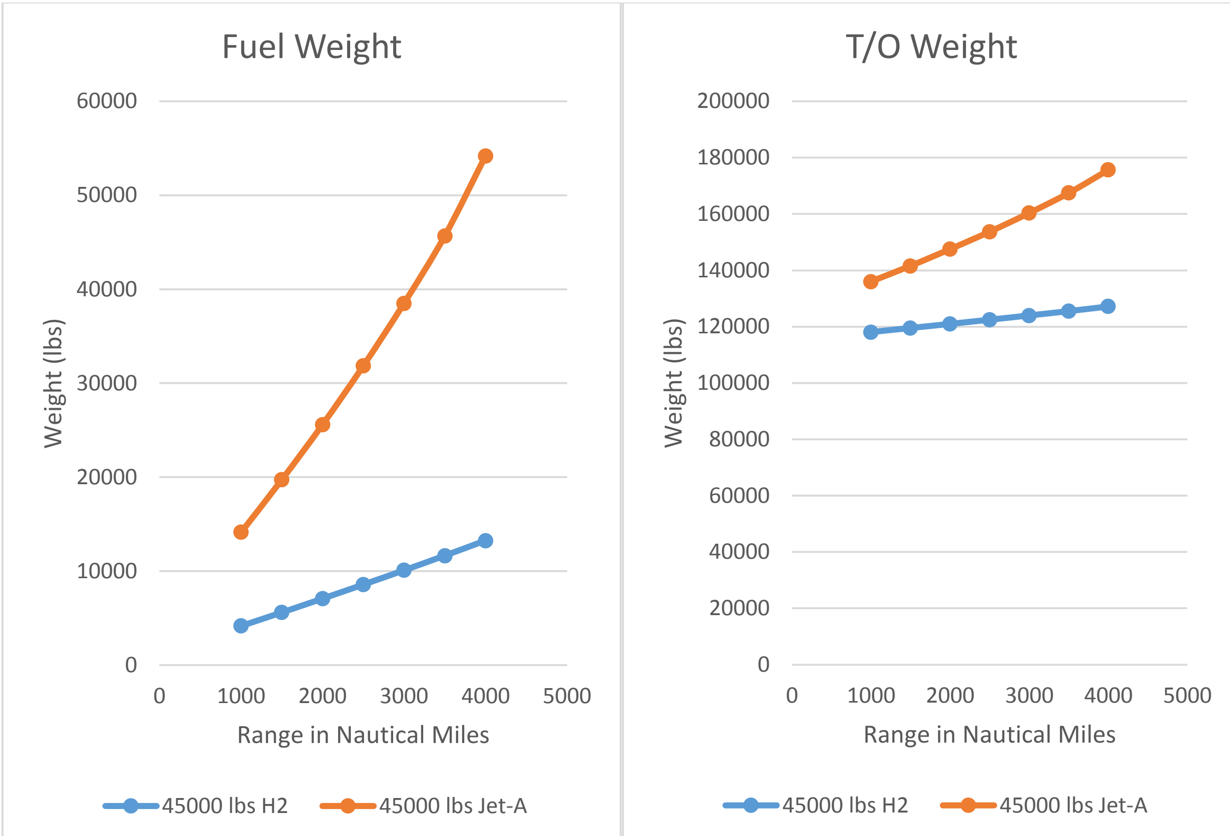

Figure 33: Takeoff weight and Fuel Weight for 45000lb payload

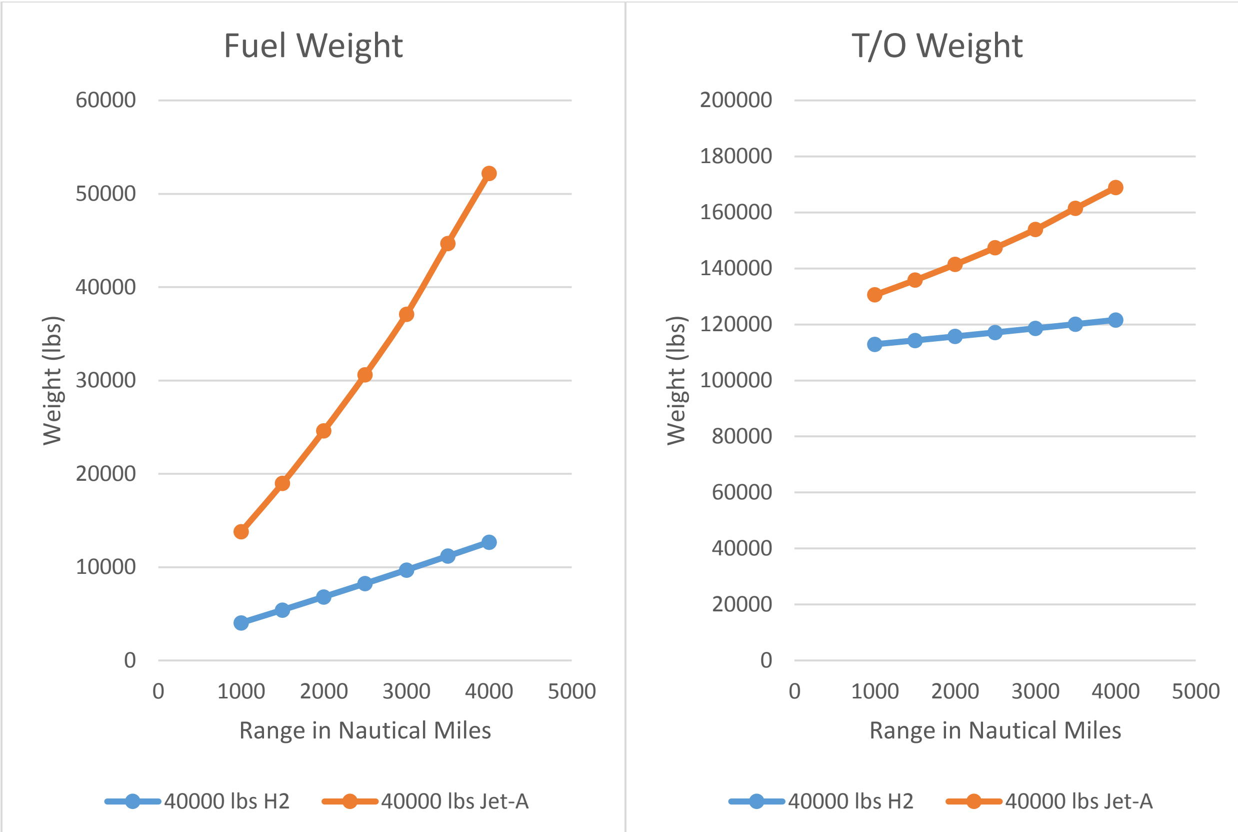

Figure 34: Takeoff weight and Fuel Weight for 40000lb payload

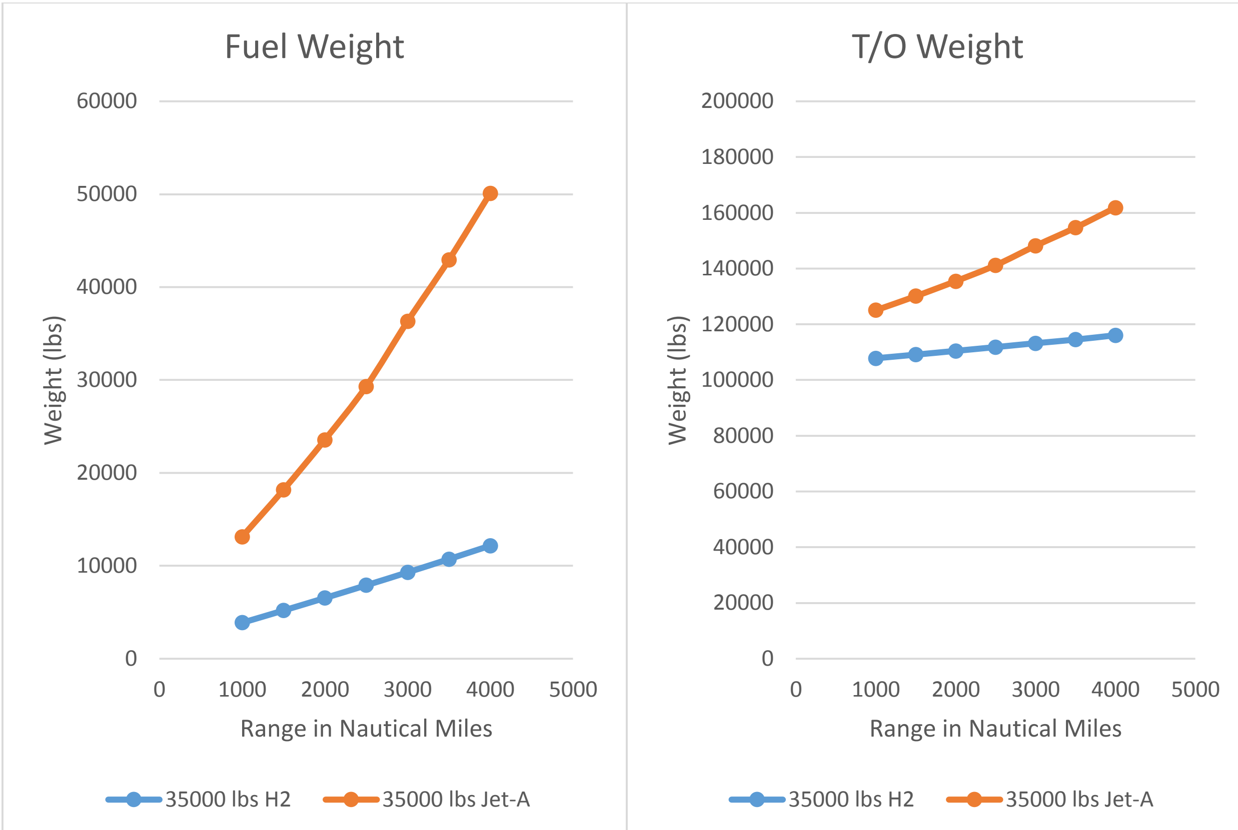

Figure 35: Takeoff weight and Fuel Weight for 35000lb payload

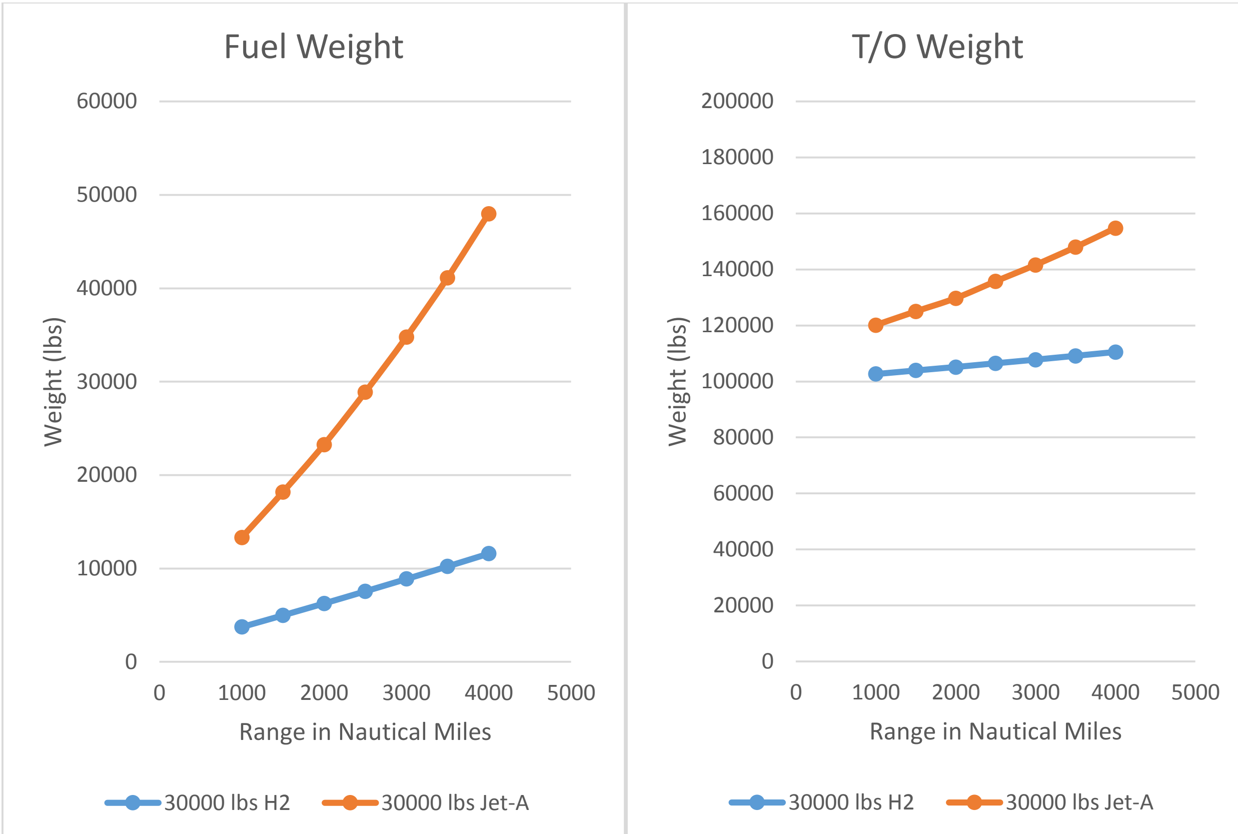

Figure 36: Takeoff weight and Fuel Weight for 30000lb payload

As a result of the hydrogen fuel being much higher in energy density when measured by weight, the hydrogen-fueled aircraft was considerably lighter and used less fuel (by weight) to accomplish the same missions.

The missions that were flown followed the following scheme: Climb → Cruise → Descend →Loiter. The profile of the design missions are described in Table 10 below.

Phase	Start Mach No.	End Mach No.	Start Alt (ft)	End Alt (ft)	Fuel Burned (H2) lbs
Warm up	0	0	0	0	143.6
Takeoff	0	0.20	0	0	35.2
Climb	0.20	0.46	0	10000	190.1
Accelerate	0.46	0.51	10000	10000	17.1
Climb	0.51	0.72	10000	35065	1420.1
Cruise	0.72	0.75	35065	35065	10918.1
Descent	0.75	0.32	35065	1500	0
Loiter	0.32	0.3	1500	1500	809.1
Landing	0.3	0.2	1500	0	0

Table 10: Mission definition for H2 aircraft

Phase	Start Mach No.	End Mach No.	Start Alt (ft)	End Alt (ft)	Fuel Burned (Jet-A) lbs
Warm up	0	0	0	0	467.3
Takeoff	0	0.23	0	0	115.6
Climb	0.23	0.46	0	10000	974.9
Accelerate	0.46	0.51	10000	10000	86.0
Climb	0.51	0.75	10000	29708	6631.2
Cruise	0.75	0.75	29708	29708	42572.8
Descent	0.75	0.33	29708	1500	0
Loiter	0.33	0.3	1500	1500	2750.9
Landing	0.3	0.22	1500	0	0

Table 11: Mission definition for Jet-A aircraft

The tables show slight differences because the ACS code calculated the mission profile using the weight of the aircraft. Because the weights of the aircraft were so different the missions ended up being defined differently. The ACS code calculated the range-optimum cruise altitude, and as a result of differing weights these ended up noticeably different. [14] The loiter phase can be optimized for the time optimum altitude and Mach number, however for this first run they were hard set at the values above. The design mission was a 4000 nautical mile mission with a 30 minute loiter time, and a 45000lb payload.

Another consideration for this system is the takeoff run distance. This is of interest to the system as it may open other less used airports for use and expand the system usability and scope. ACS Computes the FAR Takeoff Field Length for each of these aircraft. The Landing Field Length is also calculated. A summary of the estimated take-off and landing field lengths for the design mission are shown below.

Aircraft	FAR Takeoff Field Length (ft)	Landing Field Length (ft)
H2	4717	4882
Jet-A	7710	6057

Table 12: T/O and Landing Distances

4.4. Adjustments

4.4.1. Aerodynamic and weight adjustments.

The first section shown the difference in fuel type on identical aircraft. However, there are unaccounted for differences between the two aircraft that this section tries to address using the ACS tool. [14] The first problem is that the fuel itself is very different in its properties and needs. The hydrogen tanks need to be pressurized and insulated, whereas the jet fuel does not. These restrictions cause the hydrogen tanks to require more structural weight to account for this. All the jet fuel needed for this mission can be stored in the wings. The hydrogen must use fuselage tanks in addition to what can fit in the wings, assuming cylindrical vessels or pillow tanks in the wings. These differences cause the Jet-A aircraft not to need the fuselage tanks and they can be removed and the fuselage shortened. The following figures show the difference in necessary size. The reduction in sized causes the C_{D0} to decrease.

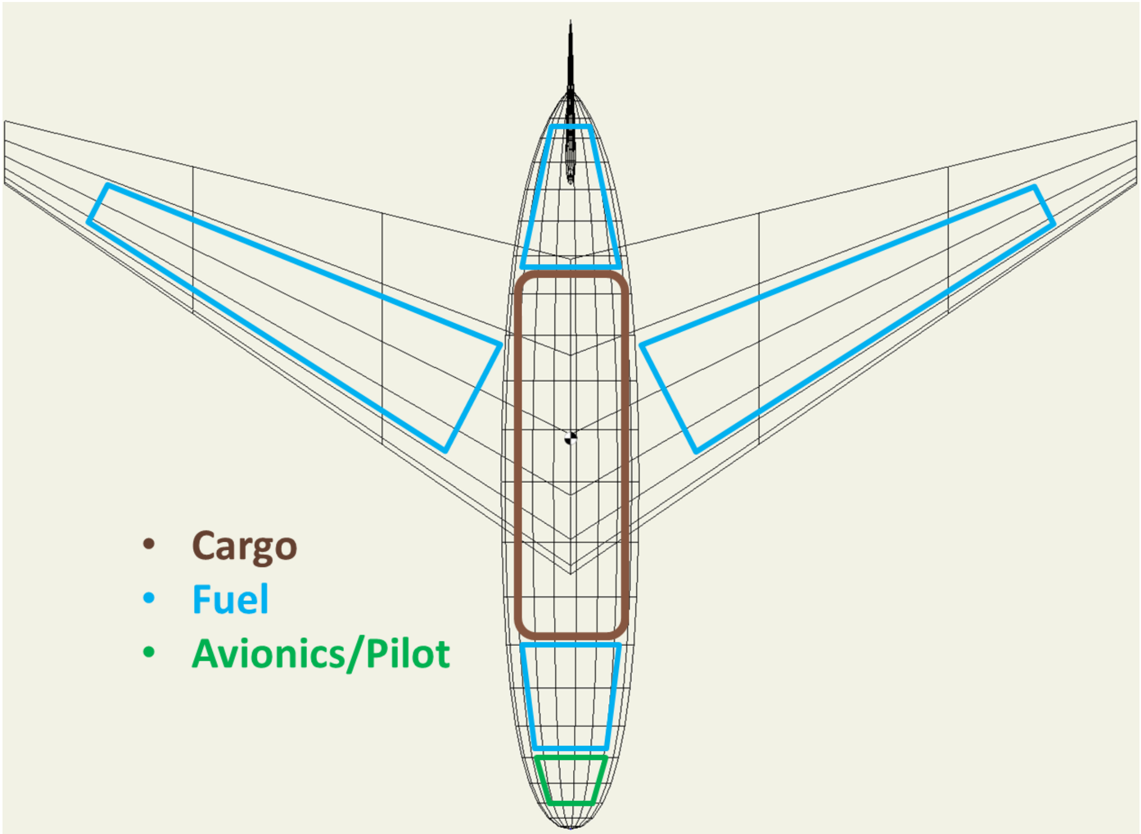

Figure 37: H_2 configuration (Not to Scale)

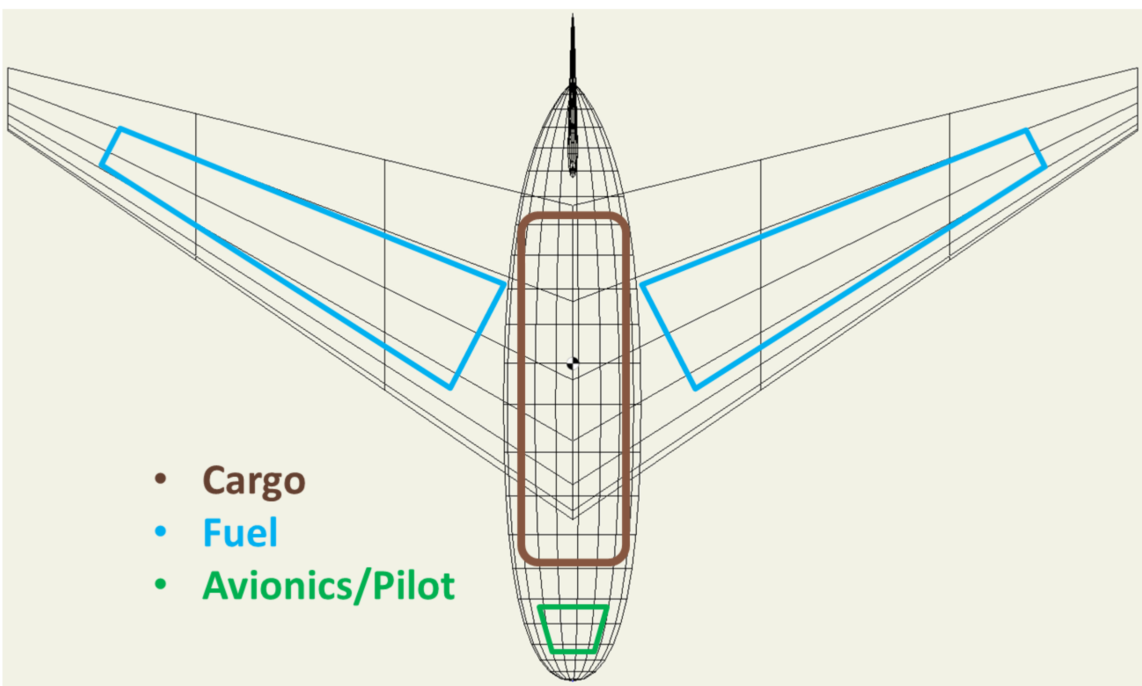

Figure 38: Jet-A configuration (Not to Scale)

The other consideration is that the fuel system for the Hydrogen aircraft will add additional weight to the aircraft. In order to estimate this weight addition for the aircraft, it is assumed that the aircraft would use technology already used. Ball Aerospace designed and built fuel tanks for the Boeing Phantom Eye. These tanks were lightweight, and as was shown earlier had a high H_2 weight percentage as compared to the total tank weight. The design weight of the 5.1" spray on foam insulation (SOFI) was predicted to be 700 lbs empty weight. After manufacturing the tanks the actually weight of the system installed on the Phantom Eye was only 615 pounds and 4.6" thick (system includes two tanks and piping for Phantom Eye). Implementing this design to the HWB would look similar to figure 39 below. The total tank volume was 16,000 Liters, made up of two 8000 Liter tanks. This translates to approximately 565 ft^3. Assuming the volume of the hydrogen vehicle from the previous run would likely be too low as a result of the increased weight from the fuel system. The volume with an additional 15% margin required just over six of the Ball Aerospace systems. Seven of the systems used in the Phantom Eye are shown below in blue. The Ball Aerospace tanks also complied with the boil off requirements of the HALE Phantom Eye. These requirements are likely more strict than this system would need, adding extra margin to the system.

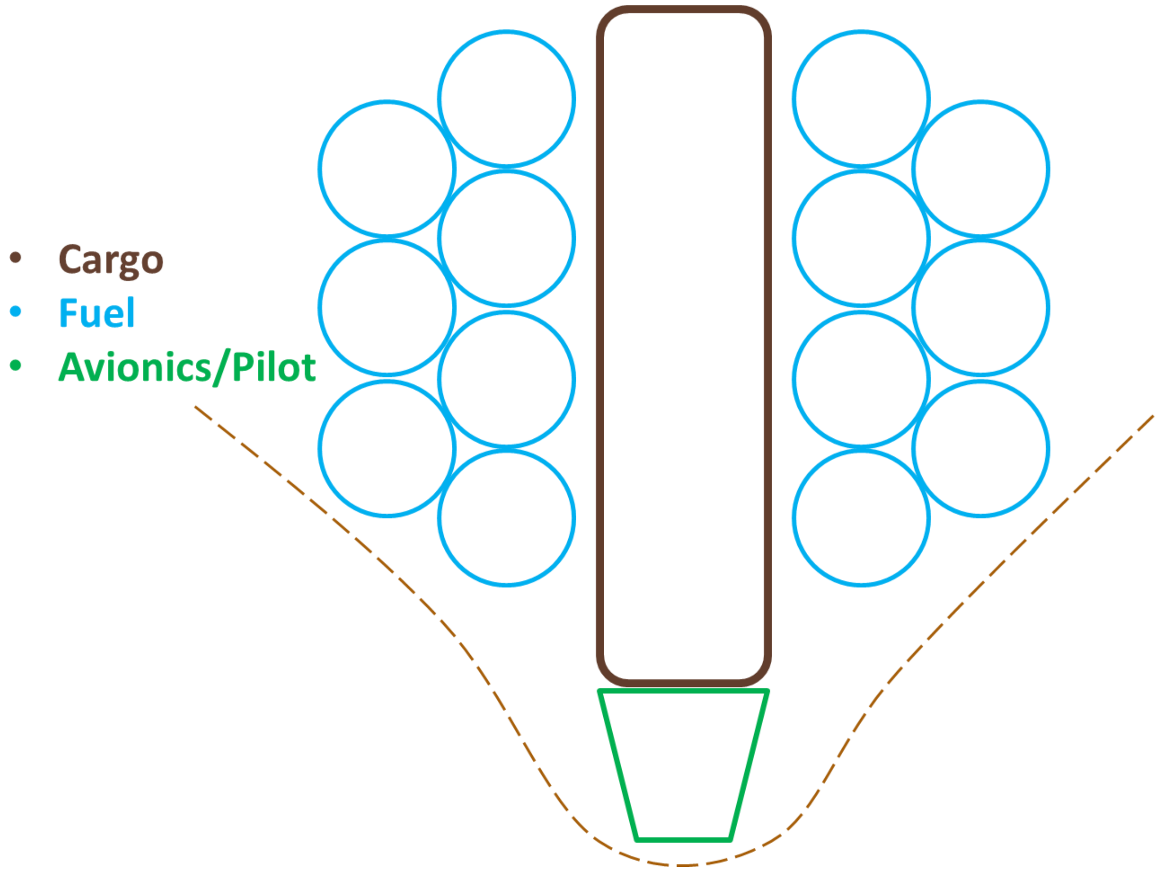

Figure 39: Potential Fuel configuration (Approximately to scale)

In a mature system, Ball Aerospace could be contracted to create cylindrical tanks that would more efficiently use the volume and the system volume would reduce the system. In this study it is assumed that seven of the Phantom Eye Tank systems are used. To be clear a “system” refers to two tanks, so a totally of 14 tanks would be used. This equates to 4305lbs for the fuel system. To account for additional fuel lines to connect the systems the weight was increased in the ACS runs to 4500lbs. The design mission was developed in a similar fashion, but the loiter time was lengthened to an hour from 30 minutes.

Variable	ZH-001b (hydrogen)	ZH-002b (Jet Fuel)
Wing area	2500 ft^2	2500 ft^2
Wing AR	6	6
Wing Sweep (1/4 chord)	30°	30°
Wing Taper Ratio	0.2	0.2
Fuselage Length	80 ft	60 ft
Fuselage Max Diameter	15 ft	15 ft
Internal Fuselage Volume	7359 ft^3	5556 ft^3
Design Mission Fuel Volume	3355 ft^3	1010. ft^3
Design Mission Fuel Weight	14839 lbs	50485 lbs
Design fall out Range	4000 nm	4000 nm
MTOW	133376 lbs	164863 lbs
Payload Weight	45000 lbs	45000 lbs

Table 13: Revised Aircraft Characteristics

As can be seen in Table 13 the MTOW of the hydrogen plane increased and the MTOW of the Jet-A aircraft decreased. The difference in weight was decreased from approximately 50,000lbs to just over 30,000lbs. The fuel weight decreased in the Jet-A aircraft by around 4,000lbs and the rest of the weight savings came from decreased structural weight. The FAR field lengths for both takeoff and landing were also changed as a result of the aircraft changes. The details of the field lengths are listed in Table 14.

Aircraft	FAR Takeoff Field Length (ft)	Landing Field Length (ft)
H2	5025	5091
Jet-A	6998	5417

Table 14: Revised T/O and Landing Distances

The engine thrust on these aircraft were set at 20,000lbs each as the C-130 engine did a similar amount of thrust. The ACS tool used a few different types of engines to serve as a base line for engine computation. A Pratt & Whitney JT9D was used as a baseline with the thrust and size decreased. The P&W engine had a high bypass ratio similar to the new engines of today. The engine was sized matching the C-130 and taking other general trends from the GE CF-34.

Another method used to compare the new designs was assuming maximum fuel and then determining the fall-out range. This is part of the reason behind extending the loiter time to 60 minutes. ACS cannot account for some of the regulations that the FAA imposes, such as the need to be able to reach another airport in case of being diverted. The FAA requires a 30 minute loiter during the day be accounted for and a 45 minute loiter during the night. A 60 minute loiter was used to help account for some of the requirements the tool could not simulate. The following graph shows the range vs. payload for both aircraft.

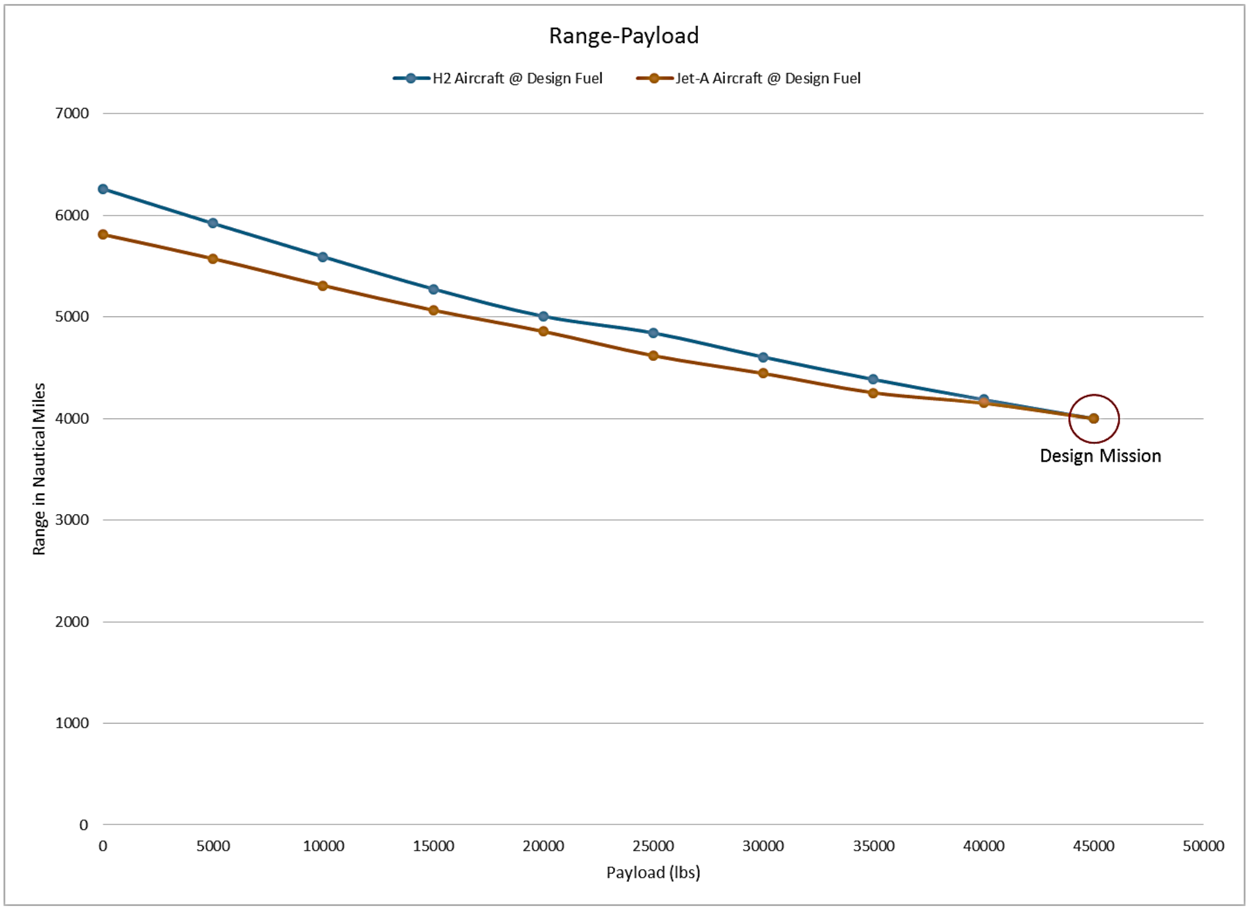

Figure 40: Range-Payload Curve

4.4.2. Re-Engined Versions

4.4.2.1. PW6000

The PW6000 engine is an engine similar to the engine approximation used in the previous section. The engines parameters have been entered into the propulsion modules of each file. The rest of the variables were held constant with the exception of the geometry module being changed to accommodate a different size engine. The PW6000 offered higher thrust but is much heavier than the engine approximated from the C-130. The simulation run by ACS approximates the engine as a modification of engines it has programed in. The following is the aircraft parameters output from this modification. [9]

Variable	ZH-001b (hydrogen)	ZH-002b (Jet Fuel)
Wing area	2500 ft^2	2500 ft^2
Wing AR	6	6
Wing Sweep (1/4 chord)	30°	30°
Wing Taper Ratio	0.2	0.2
Fuselage Length	80 ft	60 ft
Fuselage Max Diameter	15 ft	15 ft
Internal Fuselage Volume	7359 ft^3	5556 ft^3
Design Mission Fuel Volume	3563 ft^3	1139 ft^3
Design Mission Fuel Weight	15758 lbs	56971 lbs
Design fall out Range	4000 nm	4000 nm
MTOW	140166 lbs	178105 lbs
Payload Weight	45000 lbs	45000 lbs
FAR Takeoff Field Length (ft)	4810	6889
Landing Field Length (ft)	5334	5802

Table 15: PW6000 Aircraft Characteristics

The different engine increased the weight over the approximated engine used earlier. Both aircraft increased in weight and needed to burn more fuel. Interestingly, the takeoff distances decreased for both aircraft despite higher MTOW. This is due to the higher thrust. The landing field length was lengthened as a result of higher touchdown velocities and weight.

4.4.2.2. GE CF-34

The GE CF-34 engine was used for some variables in the engine approximation used in the first runs. In this section the actual variables were used and the ACS tool approximated the engine using the specification of the GE CF-34 by taking engines it has programed in and scaling them appropriately. The thrust value for this engine is lower but the weight is also less. Table 16 sums up the aircraft characteristics using the GE CF-34. [10]

Variable	ZH-001b (hydrogen)	ZH-002b (Jet Fuel)
Wing area	2500 ft^2	2500 ft^2
Wing AR	6	6
Wing Sweep (1/4 chord)	30°	30°
Wing Taper Ratio	0.2	0.2
Fuselage Length	80 ft	60 ft
Fuselage Max Diameter	15 ft	15 ft
Internal Fuselage Volume	7359 ft^3	5556 ft^3
Design Mission Fuel Volume	3460 ft^3	1064 ft^3
Design Mission Fuel Weight	15302 lbs	53178 lbs
Design fall out Range	4000 nm	4000 nm
MTOW	135446 lbs	169051 lbs
Payload Weight	45000 lbs	45000 lbs
FAR Takeoff Field Length (ft)	5097	7213
Landing Field Length (ft)	5162	5529

Table 16: GE CF-34 Aircraft Characteristics

Using the GE engine gave similar results to the approximated engine in the first iteration. The takeoff run for the hydrogen powered aircraft was approximately the same length, although the landing field length was slightly longer. For the Jet-A aircraft the takeoff run and landing are longer than the approximated engine. For both of these aircraft the takeoff runs were longer than with PW6000 but the landing field lengths were shorter. The MTOW and fuel weight for both aircraft was less than the PW6000 but increased from the approximated engine.

4.4.3. Engine notes

The ACS program uses engines that it has programed in to approximate the engines that are input. While it is possible to input the actual engine characteristics, such as compressor efficiency, these details are not often available to the public, especially on new products. The resulting approximations of the engines are not necessarily representative of the final design. The ACS tool uses dated engine designs and calculations. The CFM International LEAP engine boasts 15% fuel savings over current engines, and would likely be lighter than the fifteen-year-old PW6000 [11]. The engines approximated and run above are 15 years-old for the PW6000 and over thirty years for the GE CF-34 engine. The effects of new technologies and materials in the engines can only be theorized, but if the CFM LEAP engine indeed offers 15% less fuel burn then the impacts on the design weight and fuel burn would be significant. While ACS cannot provide a more updated output, the goal of this study is to determine the feasibility and advantages of a hydrogen powered aircraft by comparing H_2 and Jet-A aircraft in the conceptual design phase. For this purpose, the ACS tool is effective.

The final design will likely contract an engine manufacturer to design an engine specifically for the Aircraft. Because of the unique fuel source (hydrogen) a new engine will likely need to be designed to optimize the performance. One potential for engines using liquid Hydrogen as a fuel source is that the cryogenic liquid could serve as a pre-cooler or and intercooler in a turbine engine. In order to achieve higher efficiency in a turbine engine the Overall Pressure Ratio should be as high as possible. As the OPR increases the SFC of the engine increases. The problem faced with increasing the OPR is that as the pressure increases so does the temperature. Too high a temperature can result in material failure. One possible way to increase the OPR without risking failure of materials in the turbine, is to cool the gas before the compressor or in between the compressor stages. This way some of the heat is removed allowing for further compression and a higher OPR. This has traditionally been unfavorable due to the weight and complexity of adding a cooler. However, in this design the cryogenic H_2 must be warmed and evaporated to be burned. If the hydrogen were heated via a heat exchanger after the first stage compressor this would allow the hydrogen to be boiled into gaseous form and allow the hot air to be cooled potentially allowing for lower SFC. This design doesn't need a large amount of extra equipment to accomplish this and is less likely to result in higher weights and complexities. The initial configuration is not likely to have this as it has not yet been developed. The system would likely start on a minimally modified existing engine and then at a later state of maturation move to the cooled engines.

4.5. Aircraft Scaling

The aircraft talked about so far has been based on a C-130 sized aircraft. The useful load of around 4500 pounds and around 4000 ft^3 of cargo volume. For the system to be effective at a range of city sizes and therefore a range of cargo, a range of aircraft sizes is desired. The aircraft defined has a long range and a high cargo load. Aircraft currently used for commercial freight are sized even larger such as the 777F and the 747-8F. For these reasons and the desire to enable more airports (with smaller runways) to use this system, the following aircraft will be scaled down (as opposed to up and down). After the system has matured the possibility exists for a larger intercontinental H_2 powered HWB's, but these are outside the scope of this study.

For this study, three aircraft sizes were chosen to fulfil the systems capabilities. The details of these aircraft are listed below.

Variable	Large	Mid-sized	Small
Payload (lbs)	45,000	10,000	2,000
Cargo area (ft^3)	4,000	1,000	350
Design Fallout Range (nm)	4,000	2,000	1000

Table 17: Summarizing Aircraft sizing

4.5.1. Mid-sized Aircraft

The midsized aircraft is designed to be similar to an ATR-72 size, but with extended range. While not as long as the large aircraft, this aircraft still provides mid to long range delivery while being able to fly into smaller airports. The decreased cargo capacity is consistent with the fact that smaller airports tend to be in smaller cities/towns which have less shipping needs. The aircraft data is summarized below.

Variable	ZH-101 (hydrogen) mid-sized
Wing area	1000 ft^2
Wing AR	6
Wing Sweep (1/4 chord)	30°
Wing Taper Ratio	0.2
Fuselage Length	50 ft
Fuselage Max Diameter	9 ft
Internal Fuselage Volume	1649 ft^3
Design Mission Fuel Volume	667 ft^3
Design Mission Fuel Weight	2950 lbs
Design fall out Range	2000 nm
MTOW	35860 lbs
Payload Weight	10000 lbs
FAR Takeoff Field Length (ft)	3040
Landing Field Length (ft)	3811

Table 18: Mid-Sized Aircraft Characteristics

This Aircraft is considerably smaller than the first design and as a result the fuel burned is considerably less. The FAR takeoff field length also is shortened to the point in which many airports and cities could be serviced by this aircraft that could not be serviced by the larger aircraft. The fuel system weight was determined in a similar fashion to the large aircraft. The design fuel volume can be achieved through using 1.5 of the Ball Aerospace systems. The fuel system consists of two tanks allowing for the system to easily be split in half by only using one tank. Three tanks will be sufficient to hold the necessary volume. This weight come out to 923lbs, but to account for extra pipes linking the fuel tanks a weight of 1000lbs was used.

The engine for this ACS run was a Rolls-Royce AE 3007. The 3007 had less than half the thrust of the previous engines used but was also considerably lighter than the CF-34 or PW6000. Figure 41 shows the range payload curve of this aircraft at the design fuel. The fully loaded fall out range of the aircraft was an input design variable set at 2000 Nautical miles. The zero payload or "ferry flight" condition was close to 2850 nautical miles. The mission design was similar to the large aircraft, but with a decreased range. The cruising altitude increased to approximately 42,000 feet, as a result of the lighter aircraft.

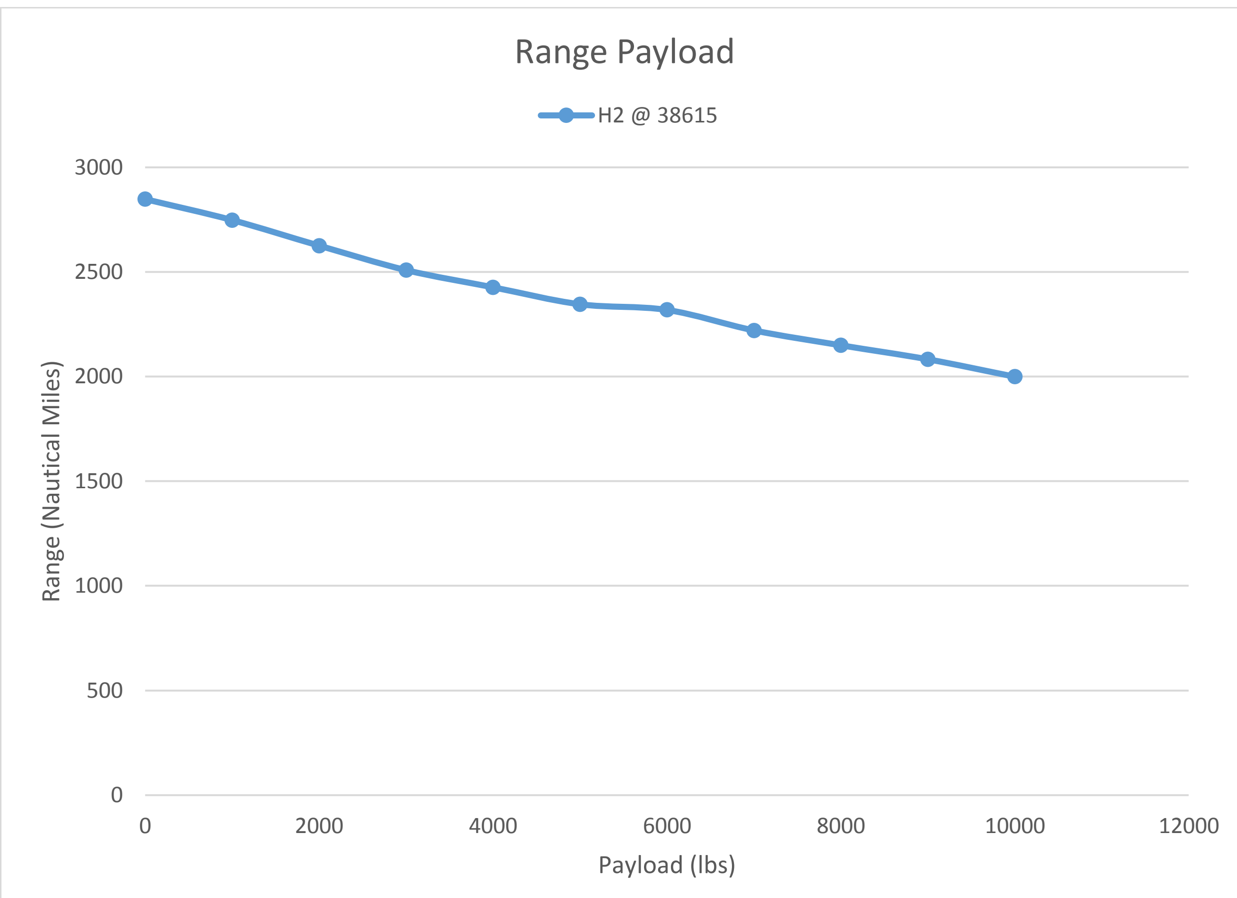

Figure 41: Range-Payload Curve for Mid-Sized Aircraft.

4.5.2. Small Aircraft

The last size of aircraft that will be looked at is a small aircraft to carry cargo to smaller airports. This aircraft will require a much smaller payload weight and volume as the airports it will fly to service smaller populations. The aircraft will also have a smaller range for flight. The range for this aircraft will be 500 nautical miles. However, because this aircraft will service smaller airports, the fuel infrastructure may not be there to refuel the aircraft. As a result the design range was doubled to help account for this. While simply doubling the range does not allow for a 500 nm "there and back" flight, it does leave a considerable margin. There is also the potential to attach external fuel tanks in case of a 500 nm "there and back" flight.

The configuration of this aircraft is different than the other two sizes. Because of the smaller aircraft size, only one engine was placed in the center above the fuselage. Two vertical tails were used as a result. The layout of this aircraft is shown below. Another change in this aircraft is the mission trajectory was modified. Instead of a cruise Mach number of 0.75 (low transonic), the cruise Mach number was lowered to 0.65. For a smaller aircraft it is not necessary to travel that fast, and the resulting cruise altitude during flights with that high a Mach number was close to 50,000 ft.

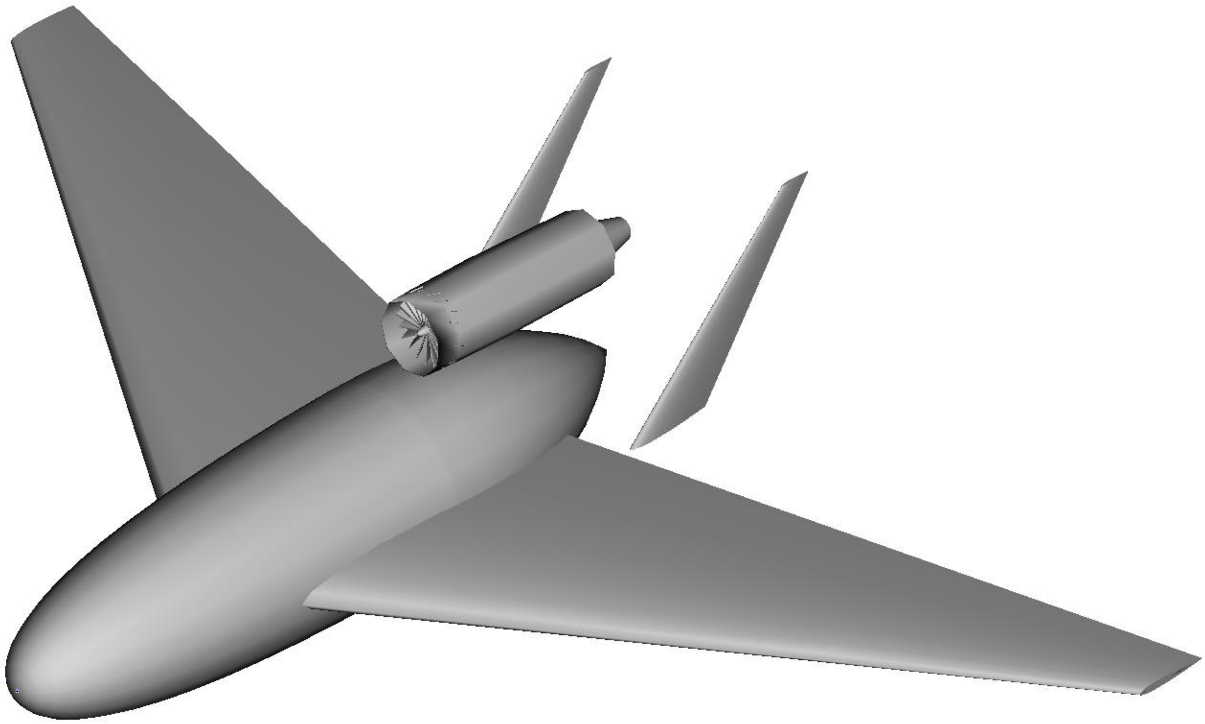

Figure 42: Small Aircraft Configuration.

The performance variables of this small size aircraft are listed below. The FAR field lengths for this aircraft are very short. This aircraft can make a safe takeoff and landing on runways smaller than 3000 ft. This allows this aircraft to service most paved runways.

Variable	ZH-101 (hydrogen) mid-sized
Wing area	550 ft^2
Wing AR	6
Wing Sweep (1/4 chord)	30°
Wing Taper Ratio	0.2
Fuselage Length	30 ft
Fuselage Max Diameter	7.5 ft
Internal Fuselage Volume	713 ft^3
Design Mission Fuel Volume	207 ft^3
Design Mission Fuel Weight	917 lbs
Design fall out Range	1000 nm
MTOW	16374 lbs
Payload Weight	2000 lbs
FAR Takeoff Field Length (ft)	2395
Landing Field Length (ft)	2815

Table 19: Small Aircraft Characteristics

For this aircraft, one AE 3007 was used for propulsion. This required the vertical tail to be split into two tails. The fuel system weight was approximated by only using one of the Ball Aerospace Tanks (half the total system weight). Only one tank allows for 282 ft^3 while the aircraft only requires 207 ft^3. Half the system weight was 308lbs. Because the spherical shape and size is not favorable in this case, the fuel system weight was increased to 350lbs despite the

282 ft^3 being larger than what was needed. The graph below shows the range of the aircraft vs. the payload.

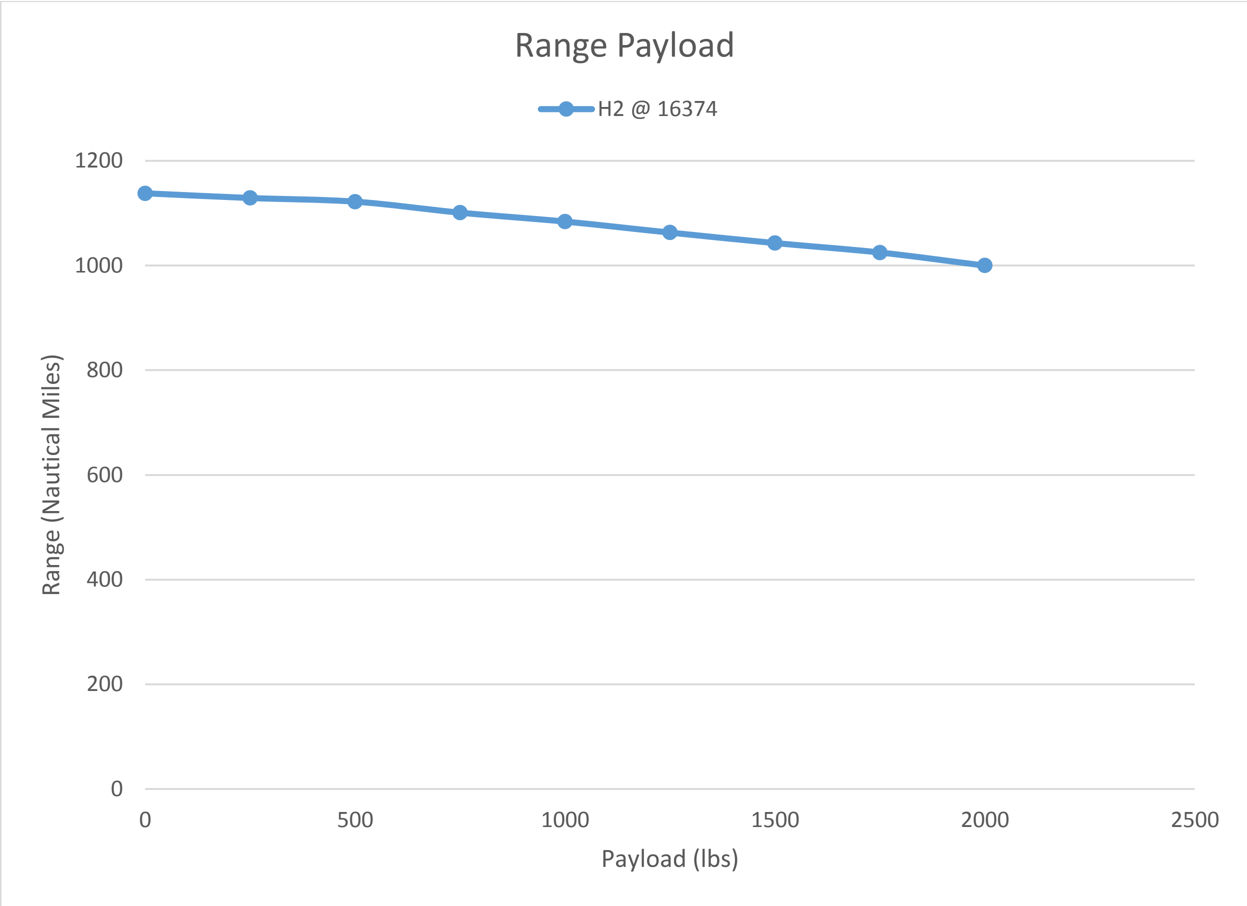

Figure 43: Range-Payload Curve for Small Aircraft.

4.5.3. Aircraft Scaling Summary

The different aircraft fulfill different roles in the transport of cargo from one location to the next. Because of the variance in cities sizes and therefore variance in cargo needs, a range of aircraft are needed. The different aircraft are compared in the following figures.

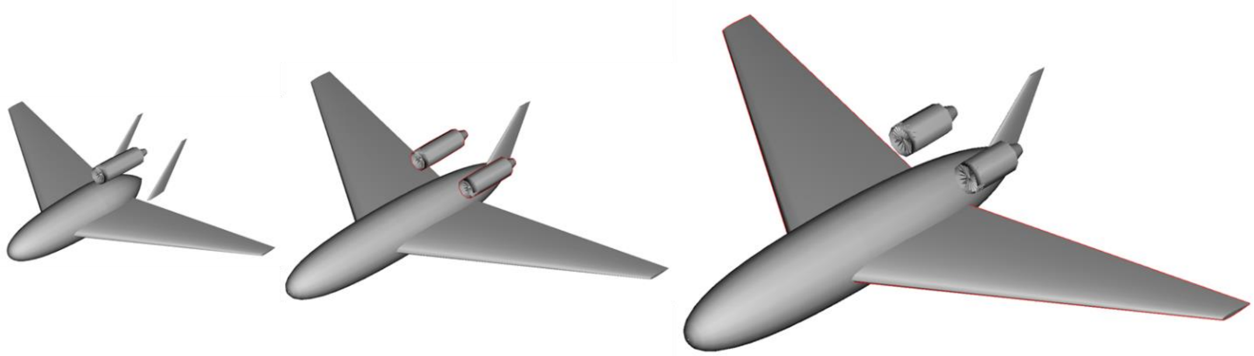

Figure 44: Aircraft Sizes Approximately To Scale.

The above figure shows the output of the ACS program with turbine engines added using the dimensions of the engines used.

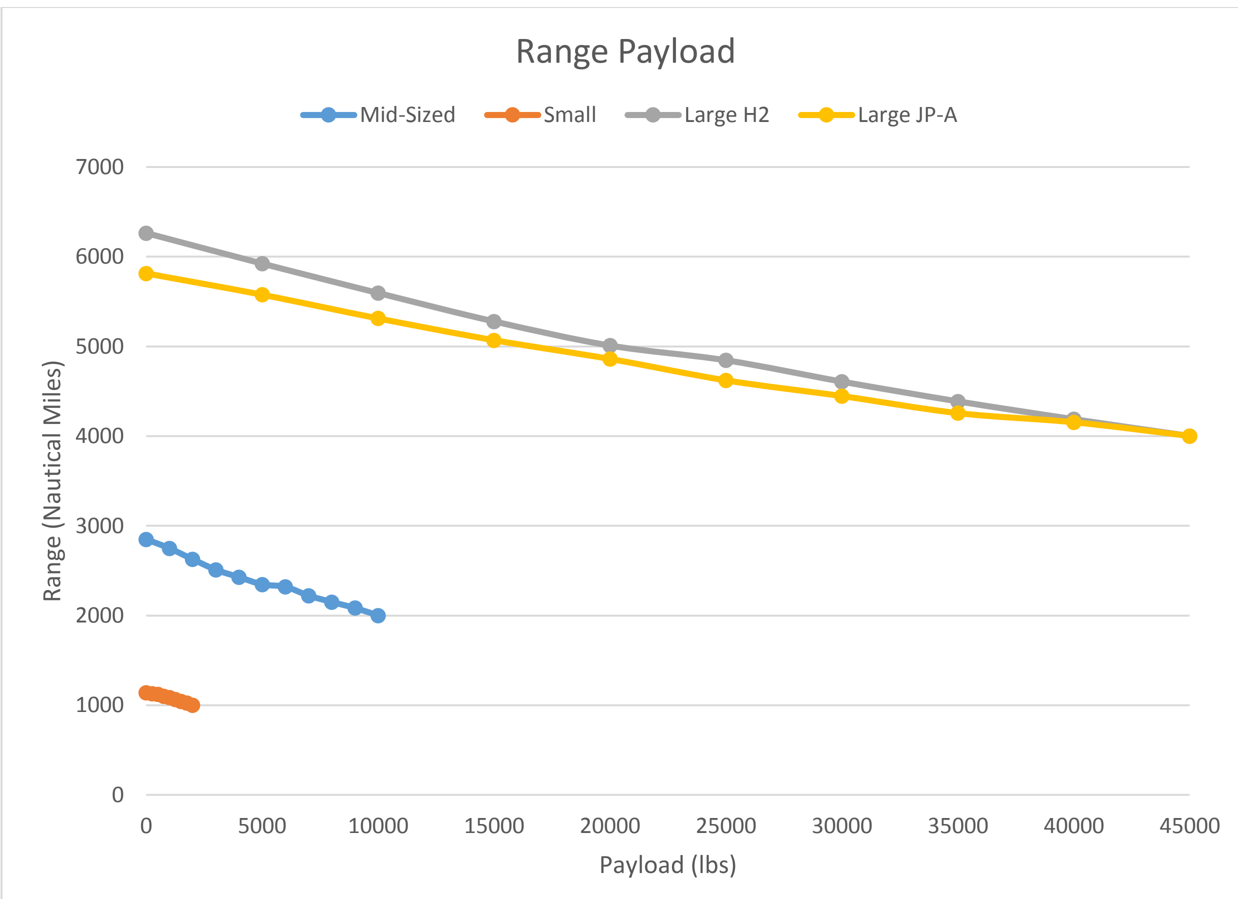

Figure 45: Aircraft Range-Payload Comparison.

This figure shows the different ranges and payloads each vehicle can operate in. This gives perspective on the different missions these aircraft might undertake.

4.6. Adjustments/comments

The aircraft evaluated in the previous sections was different from a hybrid wing body in a few ways that in future studies may need to be accounted for. This study shows the feasibility of this system against a similar system using fossil fuels. Many of the differences between this system and a HWB design for this mission are favorable towards the system.

The weight differences are the most prominent. ACS estimates the weight based on a metal aircraft that is not span loaded. The HWB allows for lesser bending moments because of the lift from the fuselage and the distribution of weight. If current structural technology were implemented, and a HWB was used the structural weight of the aircraft would decrease.

Aerodynamics would also vary between an HWB and the approximation. An HWB would have more wing area and this could potentially shorten takeoff/landing distances by reducing the stall speed. The all wing design of a HWB would also be less suited for higher transonic speeds. The HWB would likely have to travel slower to avoid excess drag.

A HWB also has other benefits over the approximation. The above wing engine mounting allows the HWB to reduce its sound profile. This will allow the system to be more attractive to regions that value quiet airways. The HWB also has excess volume and this is convenient for liquid hydrogen storage.

5. CHAPTER 5: CONCLUSIONS AND FUTURE WORK

5.1. Future Work

The level 0 system has been looked at from a big picture stance, but each level 1 system needs to be explored. The cargo system should be studied and optimized for logistics. The Power system needs to be investigated by power engineers. Perhaps the most interesting remaining study is of the Fuel Infrastructure. The electrolysis of water and the potential use of electrolytes is an unexplored area that certainly needs to be explores for the system to be complete. These level 1 systems generate interface requirements for the flight system.

On the level 1 Flight system there is still work to be done. Design teams to take each component and optimize it to perform well, companies to outsource the avionics or engine design to, and further trade studies all need to be accomplished before this system could be sold. The following is a list of potential trade studies that could be implemented to further advance the system.

- Emissions trade study using different potential renewable fuels (ethanol, electric, biodiesel, etc.)
- Form of Hydrogen: high pressure, liquid, or slush hydrogen for use in a hydrogen system
- What form of energy to use for the Level 1 Power System: wind, solar, geothermal, tidal, hydroelectric, or nuclear
- Tradeoff between takeoff run length and fuel savings: see if some takeoff run length could be sacrificed to improve fuel savings.
- Engine number: how many engines do the variants need to optimize on both efficiency and safety?
- Engine type: High bypass Turbo-Fan, Propfan, Turbo-prop, piston prop. Which gives best SFC?

- Aircraft configuration: HWB, lifting body, High aspect ratio, or more exotic designs such as annular wings, or high aspect ratio joined tandem wings. Do any of these designs optimize safety, efficiency, and manufacturability?
- On a level 2 system such as aircraft power systems: Is it more efficient and safe to use all electric, electro hydrostatic actuators, or full hydraulics system for flight controls?

More in-depth multi-disciplinary optimization using CFD and FEA can be used to more accurately zero in on actual aerodynamic and weight data to use in fuel calculations.

5.2. Emissions

As this System concept is to be a Green System, reducing emissions is of paramount importance. The decrease in aircraft weight translates to lower energy needed to fly the aircraft. The question becomes what are the actual emissions of hydrogen and Jet-A fuel. While hydrogen is often cited as a "zero emissions" option, that is not strictly true. NO_x is emitted as a result of the heat in burning. However, NO_x is the only greenhouse gas emitted by hydrogen burning. A summary of the emission of kerosene and hydrogen burning is tabulated below. Kerosene is almost identical to Jet-A fuel in its chemical properties.

Fuel type (Equal Energy)	Water	N_2	CO_2	NO_x	SO_2	Soot	CO	UHC
H_2 (0.36kg)	Yes (3.21kg)	Yes (9.4kg)	No	Yes	No	No	No	No
Kerosene (1kg)	Yes (1.24kg)	Yes (11.2kg)	Yes (3.16kg)	Yes	Yes	Yes	Yes	Yes

Table 20: List of Emissions [1]

Hydrogen does not output many of the harmful pollutants that kerosene does. The water emitted from hydrogen is considerably higher than from kerosene. Water vapor is a greenhouse gas, but the residence time in the atmosphere is very short compared to CO_2. This makes greenhouse effects from water vapor negligible in comparison [1]. The question comes down to NO_x since this is the only value left to compare. According to the finding in Cryoplane, advances in kerosene burning may reduce NO_x emissions by up to 60% as compared to current kerosene burning. For hydrogen, burning the fuel lean and using something called "micromix" principle developed at FH-Aachen reduces the NO_x by an average of 75% [1]. Even the NO_x emissions from a hydrogen burning engine are less than the kerosene alternative. Hydrogen is a much cleaner and more "green" solution than the current kerosene based systems.

5.3. Conclusions

The Green Cargo transportation system offers increased efficiency and decreased emission over a Jet-A fueled counterpart. The large hydrogen vehicle had a takeoff weight 20% lighter than the Jet-A vehicle, the total fuel system weight (fuel + empty weight) was 60% less for the hydrogen vehicle (using result from GE CF-34 version). While there are still many milestones to pass in order to see the system realized, the Green Cargo Transport offers many benefits including autonomy, decreased emissions and decreased time to delivery over Jet-A fueled aircraft and Diesel powered trucks. In order to be realized the system would require significant further study and funding. Ultimately, in order to become financially competitive with the current fuel source and infrastructure, government and political support would be necessary.

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7. APPENDIX

Text inputs for ACS

ZH-001d: Large H_2 with CF-34

```
$DATA BLOCK A
BWB H2 ZH-001
$DATA BLOCK B
1
$DATA BLOCK V
END
Transport
   5    3    5 1830 1845    0    0    0    2    1    7    0
   .0001          10E8
   1    2    3    4    6
   1    2    6
   1    2    3    6    4
 ***** GEOMETRY FOR ZH-001 *****
 $WING
  AR = 6,
  AREA = 2500,
  DIHED = 5,
  FDENWG = 4.423,
  LFLAPC = 0.05,
  SWEEP = 30.0,
  SWFACT = 1.0,
  TAPER = 0.20,
  TCROOT = 0.12,
  TCTIP = 0.12,
  TFLAPC = 0.20,
  TWISTW = 0.0,
  WFFRAC = .4,
  XWING = 0.45,
  ZROOT = 0.0,
  KSWEEP = 1,
 $END

 $VTAIL
  AR = 2,
  AREA = 100.0,
  SWEEP = 45.0,
  SWFACT = 1.0,
  TAPER = 0.35,
  TCROOT = 0.1,
```

```
 TCTIP = 0.1,
 VTNO = 1.0,
 XVTAIL = 1.0,
 YROOT = 0,
 ZROOT = 3.2,
 KSWEEP = 0,
 SIZIT = .False,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
 WFUEL = 25000,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
$END

$CREW
 WIDTH = 6,
 LENGTH = 5,
 NCREW=1,
$END

$FUS
 BDMAX = 15,
 BODL = 80,
 FRAB = 6,
 FRN = 2.5,
 LRADAR = 0.0,
 SFFACT = 1.00,
 THTAB = 5,
 WALL = 0.5,
 WFUEL = 15000.0,
 ITAIL = 1,
$END

$ELEC
 LENGTH=3.0,
 VOLUME=30,
$END

$CARGO
 WNGFAC = 1,
```

```
 X = 40,
 Y = 10,
 Z = 9,
$END

$FPOD
  DIAM = 4.5,
  LENGTH = 9,
  SOD = .7,
  THETA = 40,
  X = .8,
  SYMCOD = 0,
$END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
 TIMTO1=15., TIMTO2=0.5, FRFURE=0.006, RANGE=2500.0, QMAX=400.,
 WFEXT=0.0,  WFTRAP=0.0, XDESC=100.0,  CRMACH=.75,   NLEGCR=30,
 IPSTO1=5,   IPSTO2=2,   MMPROP=1,     IPSIZE=-3,     NLEGCL=20,
 LEGRES=1,   IBREG = 1,  NMISS = 5,    NCRUSE=1,
$END
      6 45000.0
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1  4000.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 20000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 15000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
```

```
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6 10000.0   conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6  0000.0   conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

          ***** AERODYNAMICS OF THE H2 BWB *****
 $ACHAR ABOSB=0.15,  ALMAX=20.0,
          BDNOSE = 15, CLOW=10*0.3,
       ALELJ=3, ISUPCR=1,
 $END
 $AMULT CSF = 1.0,
          FCDF=1.05,
          FCDW=.6,
          FMDR=1.0,
          $END
 $ATRIM CFLAP=0.15,
          CGM= 10*0.0,
          SM = 0.09,
          SPANF= 0.75,
```

```
 $END
 $ADET  ALIN= 0.,1.0,2.0,3.0,4.0,5.0,6.0,8.0,10.0,
        ALTV= 10*25000.,
        SMN=0.25,0.55,0.60,0.65,0.70,0.75,0.80,0.82,
        ICOD=1, IPLOT=1, NALF=9, NMDTL=8, $END
 $ADRAG $END
 $ATAKE DELFLD=25.0, DELFTO=20.0,
        DELLED=10.0, DELLTO=7.0, $END
 $APRINT ECHOIN=1, ECHOUT=0, INTM=0, IPBLNT=0, IPCAN=0, IPENG=0, IPEXT=0,
        IPFLAP=0, IPFRIC=0, IPINTF=0, IPLIFT=0, IPMIN=0, IPWAVE=0, KERROR=0,
  $END
***** GENERAL ELECTRIC CF-34 TURBOFAN *****
4
 $LEWIS TWOAB=20000.,
            AENDIA=4.5,
            AENLE=9,
            AENWT=3700.,
            BA=5,
            DIA1=4.5,
        XMACH=0.0,0.6,0.65,0.70,0.75,0.85,
            ALTD=0.,5*25000.0,
            MACH1=0.85,
            SFSFC1=1.0,
            HVF = 60000,
 $END

 $INLET
  INTYPE=1,        LM=10.,     SFPRFP = 1.0,        NINL  =2,
 $END
 $AFTBD    $END
TRANSPORT
***** H2 BWB WEIGHTS *****
 $OPTS   WGTO=175000.0, TECHG = 1.0,
         SLOPE(1) = 1.00,
         SLOPE(2) = 1.20,
         SLOPE(4) = 1.00,
         SLOPE(5) = 1.00,
         SLOPE(6) = 1.00,
         SLOPE(9) = 1.00,
         SLOPE(10) =1.00,
         SLOPE(11) =1.00,
         SLOPE(12) =1.00,
         SLOPE(13) =1.00,
         SLOPE(15) =1.00,
         SLOPE(14) =1.00,
         SLOPE(16) =1.00,
```

```
$END
$FIXW   WCARGO=45000.,
      WFS = 4500.,
$END
```

ZH-002d: Large Jet-A with CF-34

```
$DATA BLOCK A
BWB Jet-A ZH-002
$DATA BLOCK B
1
$DATA BLOCK V
END
Transport
    5    3    5 1830 1845    0    0    0    2    1    7    0
    .0001           10E8
    1    2    3    4    6
    1    2    6
    1    2    3    6    4
 ***** GEOMETRY FOR ZH-002 *****
 $WING
  AR = 6,
  AREA = 2500,
  DIHED = 5,
  FDENWG = 50.0,
  LFLAPC = 0.05,
  SWEEP = 30.0,
  SWFACT = 1.0,
  TAPER = 0.20,
  TCROOT = 0.12,
  TCTIP = 0.12,
  TFLAPC = 0.20,
  TWISTW = 0.0,
  WFFRAC = .6,
  XWING = 0.40,
  ZROOT = 0.0,
  KSWEEP = 1,
 $END

 $VTAIL
  AR = 2,
  AREA = 100.0,
  SWEEP = 45.0,
  SWFACT = 1.0,
  TAPER = 0.35,
  TCROOT = 0.1,
  TCTIP = 0.1,
  VTNO = 1.0,
  XVTAIL = 1.0,
  YROOT = 0,
  ZROOT = 3.2,
```

```
 KSWEEP = 0,
 SIZIT = .False,
$END

$CREW
 WIDTH = 6,
 LENGTH = 5,
 NCREW=1,
$END

$FUS
 BDMAX = 15,
 BODL = 60,
 FRAB = 8,
 FRN = 2.0,
 LRADAR = 0.0,
 SFFACT = 1.00,
 THTAB = 5,
 WALL = 0.5,
 WFUEL = 15000.0,
 ITAIL = 1,
$END

$ELEC
 LENGTH=3.0,
 VOLUME=30,
$END

$CARGO
 WNGFAC = 1,
 X = 40,
 Y = 10,
 Z = 9,
$END

$FPOD
  DIAM = 4,
  LENGTH = 7,
  SOD = .7,
  THETA = 40,
  X = .8,
  SYMCOD = 0,
$END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$TRDATA
```

```
 TIMTO1=15., TIMTO2=0.5, FRFURE=0.006, RANGE=2500.0, QMAX=400.,
 WFEXT=0.0,  WFTRAP=0.0, XDESC=100.0,  CRMACH=.75,   NLEGCR=30,
 IPSTO1=5,   IPSTO2=2,   MMPROP=1,     IPSIZE=-3,     NLEGCL=20,
 LEGRES=1,   IBREG = 1,  NMISS = 5,    NCRUSE=1,
$END
      6 45000.0
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1  4000.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 20000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 15000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 10000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
```

```
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6  0000.0   conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

***** AERODYNAMICS OF THE Jet-A BWB *****
 $ACHAR ABOSB=0.15,  ALMAX=20.0,
         BDNOSE = 15, CLOW=10*0.3,
      ALELJ=3, ISUPCR=1,
 $END
 $AMULT CSF = 1.0,
         FCDF=1.05,
         FCDW=.6,
         FMDR=1.0,
         $END
 $ATRIM CFLAP=0.15,
         CGM= 10*0.0,
         SM = 0.09,
         SPANF= 0.75,
 $END
 $ADET  ALIN= 0.,1.0,2.0,3.0,4.0,5.0,6.0,8.0,10.0,
      ALTV= 10*25000.,
      SMN=0.25,0.55,0.60,0.65,0.70,0.75,0.80,0.82,
      ICOD=1, IPLOT=1, NALF=9, NMDTL=8, $END
 $ADRAG $END
 $ATAKE DELFLD=25.0, DELFTO=20.0,
      DELLED=10.0, DELLTO=7.0, $END
 $APRINT ECHOIN=1, ECHOUT=0, INTM=0, IPBLNT=0, IPCAN=0, IPENG=0, IPEXT=0,
      IPFLAP=0, IPFRIC=0, IPINTF=0, IPLIFT=0, IPMIN=0, IPWAVE=0, KERROR=0,
  $END
***** GENERAL ELECTRIC CF-34 TURBOFAN *****
4
 $LEWIS TWOAB=20000.,
         AENDIA=4.5,
         AENLE=9,
         AENWT=3700.,
```

```
          BA=5,
          DIA1=4.5,
        XMACH=0.0,0.6,0.65,0.70,0.75,0.85,
          ALTD=0.,5*25000.0,
          MACH1=0.85,
          SFSFC1=1.0,
          HVF = 18600,
 $END

 $INLET
  INTYPE=1,        LM=10.,     SFPRFP = 1.0,        NINL  =2,
 $END
 $AFTBD    $END
TRANSPORT
***** Jet-A BWB WEIGHTS *****
 $OPTS   WGTO=175000.0, TECHG = 1.0,
        SLOPE(1) = 1.00,
        SLOPE(2) = 1.20,
        SLOPE(4) = 1.00,
        SLOPE(5) = 1.00,
        SLOPE(6) = 1.00,
        SLOPE(9) = 1.00,
        SLOPE(10) =1.00,
        SLOPE(11) =1.00,
        SLOPE(12) =1.00,
        SLOPE(13) =1.00,
        SLOPE(15) =1.00,
        SLOPE(14) =1.00,
        SLOPE(16) =1.00,
 $END
 $FIXW   WCARGO=45000.,
 $END
```

ZH-101: Mid-sized H_2 with two AE 3007

```
$DATA BLOCK A
BWB H2 ZH-101
$DATA BLOCK B
1
$DATA BLOCK V
END
Transport
    5    3    5 1830 1845    0    0    0    2    1    7    0
    .0001           10E8
    1    2    3    4    6
    1    2    6
    1    2    3    6    4
 ***** GEOMETRY FOR ZH-101 *****
 $WING
  AR = 6,
  AREA = 1000,
  DIHED = 5,
  FDENWG = 4.423,
  LFLAPC = 0.05,
  SWEEP = 30.0,
  SWFACT = 1.0,
  TAPER = 0.20,
  TCROOT = 0.12,
  TCTIP = 0.12,
  TFLAPC = 0.20,
  TWISTW = 0.0,
  WFFRAC = .4,
  XWING = 0.45,
  ZROOT = 0.0,
  KSWEEP = 1,
 $END

 $VTAIL
  AR = 2,
  AREA = 50.0,
  SWEEP = 45.0,
  SWFACT = 1.0,
  TAPER = 0.35,
  TCROOT = 0.1,
  TCTIP = 0.1,
  VTNO = 1.0,
  XVTAIL = 1.0,
  YROOT = 0,
  ZROOT = 3.2,
```

```
 KSWEEP = 0,
 SIZIT = .False,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
 WFUEL = 5000,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
$END

$CREW
 WIDTH = 6,
 LENGTH = 5,
 NCREW=1,
$END

$FUS
 BDMAX = 9,
 BODL = 50,
 FRAB = 6,
 FRN = 2.5,
 LRADAR = 0.0,
 SFFACT = 1.00,
 THTAB = 5,
 WALL = 0.5,
 WFUEL = 5000.0,
 ITAIL = 1,
$END

$ELEC
 LENGTH=3.0,
 VOLUME=30,
$END

$CARGO
 WNGFAC = 1,
 X = 30,
 Y = 6,
 Z = 6,
$END
```

```
 $FPOD
   DIAM = 3,
   LENGTH = 6,
   SOD = .7,
   THETA = 40,
   X = .8,
   SYMCOD = 0,
 $END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 $TRDATA
  TIMTO1=15., TIMTO2=0.5, FRFURE=0.006, RANGE=2000.0, QMAX=400.,
  WFEXT=0.0,  WFTRAP=0.0, XDESC=100.0,  CRMACH=.75,   NLEGCR=30,
  IPSTO1=5,   IPSTO2=2,   MMPROP=1,     IPSIZE=-3,     NLEGCL=20,
  LEGRES=1,   IBREG = 1,  NMISS = 5,    NCRUSE=1,
 $END
       6 10000.0
        MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1  2000.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6 1000.0    conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6 0000.0    conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
```

```
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 3000.0    conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6 2000.0    conv
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.75     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.75 0.75     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.75 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

         ***** AERODYNAMICS OF THE H2 BWB *****
 $ACHAR ABOSB=0.15,  ALMAX=20.0,
         BDNOSE = 15, CLOW=10*0.3,
      ALELJ=3, ISUPCR=1,
 $END
 $AMULT CSF = 1.0,
         FCDF=1.05,
         FCDW=.6,
         FMDR=1.0,
         $END
 $ATRIM CFLAP=0.15,
         CGM= 10*0.0,
         SM = 0.09,
         SPANF= 0.75,
 $END
 $ADET  ALIN= 0.,1.0,2.0,3.0,4.0,5.0,6.0,8.0,10.0,
      ALTV= 10*25000.,
      SMN=0.25,0.55,0.60,0.65,0.70,0.75,0.80,0.82,
      ICOD=1, IPLOT=1, NALF=9, NMDTL=8, $END
 $ADRAG $END
```

```
 $ATAKE DELFLD=25.0, DELFTO=20.0,
       DELLED=10.0, DELLTO=7.0, $END
 $APRINT ECHOIN=1, ECHOUT=0, INTM=0, IPBLNT=0, IPCAN=0, IPENG=0, IPEXT=0,
       IPFLAP=0, IPFRIC=0, IPINTF=0, IPLIFT=0, IPMIN=0, IPWAVE=0, KERROR=0,
  $END
***** AE-3007 TURBOFAN *****
4
 $LEWIS TWOAB=9500.,
           AENDIA=3.2,
           AENLE=9,
           AENWT=1500.,
           BA=5.,
           DIA1=3.2,
       XMACH=0.0,0.6,0.65,0.70,0.75,0.85,
           ALTD=0.,5*25000.0,
           MACH1=0.80,
           SFSFC1=1.0,
           HVF = 60000,
 $END

 $INLET
  INTYPE=1,        LM=10.,     SFPRFP = 1.0,        NINL  =2,
 $END
 $AFTBD    $END
TRANSPORT
***** H2 BWB WEIGHTS *****
 $OPTS   WGTO=50000.0, TECHG = 1.0,
        SLOPE(1) = 1.00,
        SLOPE(2) = 1.20,
        SLOPE(4) = 1.00,
        SLOPE(5) = 1.00,
        SLOPE(6) = 1.00,
        SLOPE(9) = 1.00,
        SLOPE(10) =1.00,
        SLOPE(11) =1.00,
        SLOPE(12) =1.00,
        SLOPE(13) =1.00,
        SLOPE(15) =1.00,
        SLOPE(14) =1.00,
        SLOPE(16) =1.00,
 $END
 $FIXW   WCARGO=10000.,
        WFS=1000.,
 $END
```

ZH-201: Small H_2 with one AE 3007

```
$DATA BLOCK A
BWB H2 ZH-201
$DATA BLOCK B
1
$DATA BLOCK V
END
Transport
   5    3    5 1830 1845    0    0    0    2    1    7    0
   .0001          10E8
   1    2    3    4    6
   1    2    6
   1    2    3    6    4
 ***** GEOMETRY FOR ZH-201 *****
 $WING
  AR = 6,
  AREA = 550,
  DIHED = 5,
  FDENWG = 4.423,
  LFLAPC = 0.05,
  SWEEP = 30.0,
  SWFACT = 1.0,
  TAPER = 0.20,
  TCROOT = 0.12,
  TCTIP = 0.12,
  TFLAPC = 0.20,
  TWISTW = 0.0,
  WFFRAC = .4,
  XWING = 0.42,
  ZROOT = 0.0,
  KSWEEP = 1,
 $END

 $VTAIL
  AR = 3,
  AREA = 20.0,
  SWEEP = 45.0,
  SWFACT = 1.0,
  TAPER = 0.35,
  TCROOT = 0.1,
  TCTIP = 0.1,
  VTNO = 2.0,
  XVTAIL = 1.0,
  YROOT = .75,
  ZROOT = 0,
```

```
 KSWEEP = 0,
 SIZIT = .False,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
 WFUEL = 3000,
$END

$FUEL
 DEN = 4.423,
 FRAC = 0.5,
$END

$CREW
 WIDTH = 6,
 LENGTH = 5,
 NCREW=1,
$END

$FUS
 BDMAX = 7.5,
 BODL = 30,
 FRAB = 6,
 FRN = 2.5,
 LRADAR = 0.0,
 SFFACT = 1.00,
 THTAB = 5,
 WALL = 0.5,
 WFUEL = 3000.0,
 ITAIL = 1,
$END

$ELEC
 LENGTH=3.0,
 VOLUME=30,
$END

$CARGO
 WNGFAC = 1,
 X = 15,
 Y = 5,
 Z = 6,
$END
```

```
 $FPOD
   DIAM = 2,
   LENGTH = 4,
   SOD = .7,
   THETA = 90,
   X = .8,
   SYMCOD = 1,
 $END

$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
 $TRDATA
  TIMTO1=15., TIMTO2=0.5, FRFURE=0.006, RANGE=1000.0, QMAX=400.,
  WFEXT=0.0,  WFTRAP=0.0, XDESC=100.0,  CRMACH=.75,   NLEGCR=30,
  IPSTO1=5,   IPSTO2=2,   MMPROP=1,     IPSIZE=-3,     NLEGCL=20,
  LEGRES=1,   IBREG = 1,  NMISS = 5,    NCRUSE=1,
 $END
       6 2000.0
        MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.65     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.65 0.65     -1    -1  1000.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.65 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6  750.0    conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.65     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.65 0.65     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.65 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
       6  500.0    conv
       MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.65     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
```

```
CRUISE  0.65 0.65     -1    -1    -1.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.65 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6    0.0
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.65     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.65 0.65     -1    -1   500.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.65 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0
      6  2000.0
      MACH NO.   ALTITUDE     HORIZONTAL    NO.  VIND
PHASE   START END  START  END    DIST  TIME   TURN  "G"S  WKFUEL M IP IX W B
A P
------- ---- ----  ----- -----  ------ -----  ---- -----  ------ - -- -- - - - -
CLIMB   0.20 0.46      0 10000     0.0   0.0   0.0 250.0  1.0000 1  2 -1 0 0 0 0
ACCEL     -1 0.51  10000 10000     0.0   0.0   0.0   0.0  1.0000 1  2 -1 0 0 0 0
CLIMB   0.51 0.65     -1     0     0.0   0.0   0.0   0.0  1.0000 1  3 -1 0 0 0 0
CRUISE  0.65 0.65     -1    -1   500.0   0.0   0.0   0.0  1.0000 1  4 -1 0 0 0 0
DESCENT 0.65 0.51     -1  1500     0.0   0.0   0.0   0.0  1.0000 1  5  0 0 0 0 0
LOITER  0.30 0.30     -1  1500     0.0  60.0   0.0   0.0  1.0000 1  4  0 0 0 0 0

         ***** AERODYNAMICS OF THE H2 BWB *****
 $ACHAR ABOSB=0.15,  ALMAX=20.0,
         BDNOSE = 15, CLOW=10*0.3,
      ALELJ=3, ISUPCR=1,
 $END
 $AMULT CSF = 1.0,
         FCDF=1.05,
         FCDW=.6,
         FMDR=1.0,
         $END
 $ATRIM CFLAP=0.15,
         CGM= 10*0.0,
         SM = 0.09,
         SPANF= 0.75,
 $END
 $ADET  ALIN= 0.,1.0,2.0,3.0,4.0,5.0,6.0,8.0,10.0,
      ALTV= 10*25000.,
      SMN=0.25,0.55,0.60,0.65,0.70,0.75,0.80,0.82,
      ICOD=1, IPLOT=1, NALF=9, NMDTL=8, $END
 $ADRAG $END
```

```
 $ATAKE DELFLD=25.0, DELFTO=20.0,
       DELLED=10.0, DELLTO=7.0, $END
 $APRINT ECHOIN=1, ECHOUT=0, INTM=0, IPBLNT=0, IPCAN=0, IPENG=0, IPEXT=0,
       IPFLAP=0, IPFRIC=0, IPINTF=0, IPLIFT=0, IPMIN=0, IPWAVE=0, KERROR=0,
  $END
***** AE-3007 TURBOFAN *****
4
 $LEWIS TWOAB=9500.,
           AENDIA=3.2,
           AENLE=9,
           AENWT=1500.,
           BA=5.,
           DIA1=3.2,
       XMACH=0.0,0.6,0.65,0.70,0.75,0.80,
           ALTD=0.,5*25000.0,
           MACH1=0.80,
           SFSFC1=1.0,
           HVF = 60000,
 $END

 $INLET
  INTYPE=1,        LM=10.,     SFPRFP = 1.0,        NINL  =2,
 $END
 $AFTBD    $END
TRANSPORT
***** H2 BWB WEIGHTS *****
 $OPTS   WGTO=15000.0, TECHG = 1.0,
        SLOPE(1) = 1.00,
        SLOPE(2) = 1.20,
        SLOPE(4) = 1.00,
        SLOPE(5) = 1.00,
        SLOPE(6) = 1.00,
        SLOPE(9) = 1.00,
        SLOPE(10) =1.00,
        SLOPE(11) =1.00,
        SLOPE(12) =1.00,
        SLOPE(13) =1.00,
        SLOPE(15) =1.00,
        SLOPE(14) =1.00,
        SLOPE(16) =1.00,
 $END
 $FIXW   WCARGO=2000.,
        WFS = 350.,
 $END
```

Text Output Summaries for ACS

ZH-001d: Large H_2 with CF-34

```
SUMMARY --- ACS OUTPUT:  BWB H2 ZH-001

    GENERAL          FUSELAGE                    WING  CANARD  VTAIL
 WG    135448.   LENGTH         80.0    AREA        2500.0    0.0  100.0
 W/S      54.2   DIAMETER       15.0   WETTED AREA  4058.3    0.0  201.0
 T/W      0.30   VOLUME       7358.9   SPAN          122.5    0.0   14.1
 N(Z) ULT  3.8   WETTED AREA  3905.3   L.E. SWEEP     34.5   89.4   45.0
 CREW       1.   FINENESS RATIO  5.3   C/4 SWEEP      30.0    0.0   41.3
 PASENGERS  0.                         ASPECT RATIO   6.00   0.01   2.00
                                       TAPER RATIO    0.20   0.00   0.35
   ENGINE           WEIGHTS            T/C ROOT       0.12   0.00   0.10
                                       T/C TIP        0.12   0.00   0.10
 NUMBER     2.              W     WG   ROOT CHORD     34.0    0.0   10.5
 LENGTH    9.0   STRUCT.  40636. 30.0  TIP CHORD       6.8    0.0    3.7
 DIAM.     4.7   PROPUL.  13380.  9.9  M.A. CHORD     23.4    0.0    7.6
 WEIGHT 3700.0   FIX. EQ. 13530. 10.0  LOC. OF L.E.   27.5    0.0   69.5
 TSLS   20000.   FUEL     15038. 11.3
 SFCSLS   0.11   PAYLOAD  45000. 33.2
 ESF     1.000   OPER IT   7863.  5.8

 MISSION SUMMARY

 PHASE    MACH     ALT    FUEL   TIME    DIST   L/D    THRUST   SFC      Q
 =======  ====  ======  ======  =====  ======  =====  =======  =====  ======
 TAKEOFF  0.00      0.    195.   15.5  5096.6
 CLIMB    0.46  10000.    209.    2.9    13.1  16.95  22822.0  0.167   211.6
 ACCEL    0.51  10000.     19.    0.3     1.5  14.79  22398.0  0.174   265.0
 CLIMB    0.75  34740.   1274.   39.3   258.4  17.77   7833.8  0.193   197.8
 CRUISE   0.75  34740.  11785.  501.1  3615.7  17.01   7196.8  0.192   199.1
 DESCENT  0.33   1500.      0.   23.7   111.3  17.04      0.0  0.000   155.2
 LOITER   0.30   1707.   1476.   60.0   197.3  16.94   7137.7  0.206   125.5
 LANDING                       5161.8

 Block Time  =  9.713 hr
 Block Range = 4000.0 nm

 MISSION SUMMARY

 PHASE    MACH     ALT    FUEL   TIME    DIST   L/D    THRUST   SFC      Q
 =======  ====  ======  ======  =====  ======  =====  =======  =====  ======
 TAKEOFF  0.00      0.    195.   15.5  3853.5
```

CLIMB	0.46	10000.	165.	2.3	10.3	14.97	22822.0	0.167	211.6
ACCEL	0.51	10000.	15.	0.2	1.2	12.40	22398.0	0.174	265.0
CLIMB	0.75	39258.	1199.	45.5	296.1	17.77	6308.5	0.191	160.4
CRUISE	0.75	39258.	11777.	626.5	4492.0	16.91	5766.8	0.190	160.4
DESCENT	0.30	1500.	250.	28.4	124.3	17.07	29.8	17.757	125.1
LOITER	0.30	1740.	1357.	60.0	197.3	17.08	5637.6	0.240	125.4
LANDING			4207.1						

Block Time = 11.974 hr
Block Range = 4923.9 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	195.	15.5	3632.5				
CLIMB	0.46	10000.	157.	2.2	9.8	14.44	22822.0	0.167	211.6
ACCEL	0.51	10000.	14.	0.2	1.1	11.86	22398.0	0.174	265.0
CLIMB	0.75	39990.	1100.	42.7	275.1	17.74	6091.2	0.191	154.9
CRUISE	0.75	39990.	11932.	663.0	4753.3	16.74	5524.2	0.190	154.9
DESCENT	0.29	1500.	259.	29.5	126.8	17.07	18.4	28.535	118.5
LOITER	0.30	1743.	1300.	60.0	197.3	17.02	5355.6	0.242	125.4
LANDING			4017.4						

Block Time = 12.552 hr
Block Range = 5166.1 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	195.	15.5	3420.1				
CLIMB	0.46	10000.	149.	2.1	9.3	13.88	22822.0	0.167	211.6
ACCEL	0.51	10000.	13.	0.2	1.1	11.30	22398.0	0.174	265.0
CLIMB	0.75	41002.	1062.	43.0	275.8	17.74	5803.1	0.191	147.5
CRUISE	0.75	41002.	12060.	704.9	5054.1	16.67	5244.7	0.190	147.5
DESCENT	0.28	1500.	229.	30.8	129.9	17.08	15.2	29.242	112.2
LOITER	0.30	1747.	1249.	60.0	197.3	16.90	5094.8	0.244	125.3
LANDING			3826.3						

Block Time = 13.276 hr
Block Range = 5470.2 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q

=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	195.	15.5	3021.0				
CLIMB	0.46	10000.	134.	1.9	8.3	12.64	22822.0	0.167	211.6
ACCEL	0.51	10000.	12.	0.2	1.0	10.14	22398.0	0.174	265.0
CLIMB	0.75	43163.	970.	42.7	271.5	17.76	5227.5	0.191	132.2
CRUISE	0.75	43163.	12195.	794.8	5698.6	16.49	4692.1	0.190	133.0
DESCENT	0.27	1500.	288.	33.4	135.8	17.10	41.7	12.381	100.2
LOITER	0.30	1760.	1162.	60.0	197.3	16.43	4632.2	0.250	125.3
LANDING				3443.5					

Block Time = 14.809 hr
Block Range = 6115.0 nm

ZH-002d: Large Jet-A with CF-34

```
SUMMARY --- ACS OUTPUT:  BWB Jet-A ZH-002

    GENERAL          FUSELAGE                     WING  CANARD  VTAIL
 WG    169288.   LENGTH          60.0   AREA         2500.0    0.0  100.0
 W/S      67.7   DIAMETER        15.0   WETTED AREA  4058.3    0.0  201.0
 T/W      0.24   VOLUME        5556.4   SPAN          122.5    0.0   14.1
 N(Z) ULT  3.8   WETTED AREA   2876.1   L.E. SWEEP     34.5   89.4   45.0
 CREW       1.   FINENESS RATIO   4.0   C/4 SWEEP      30.0    0.0   41.3
 PASENGERS  0.                          ASPECT RATIO   6.00   0.01   2.00
                                        TAPER RATIO    0.20   0.00   0.35
   ENGINE           WEIGHTS             T/C ROOT       0.12   0.00   0.10
                                        T/C TIP        0.12   0.00   0.10
 NUMBER      2.             W     WG    ROOT CHORD     34.0    0.0   10.5
 LENGTH    9.0   STRUCT.  40653. 24.0   TIP CHORD       6.8    0.0    3.7
 DIAM.     4.7   PROPUL.   9620.  5.7   M.A. CHORD     23.4    0.0    7.6
 WEIGHT 3700.0   FIX. EQ. 13247.  7.8   LOC. OF L.E.   15.5    0.0   49.5
 TSLS   20000.   FUEL     52914. 31.4
 SFCSLS   0.37   PAYLOAD  45000. 26.6
 ESF     1.000   OPER IT   7861.  4.6

 MISSION SUMMARY

 PHASE    MACH    ALT    FUEL   TIME    DIST   L/D    THRUST   SFC     Q
 =======  ====  ======  ======  =====  ======  =====  =======  =====  ======
 TAKEOFF  0.00      0.    635.   15.5  7213.1
 CLIMB    0.46  10000.    914.    3.9    17.5  18.08  22913.0  0.546   211.6
 ACCEL    0.51  10000.     79.    0.4     2.0  17.74  22498.1  0.568   265.0
 CLIMB    0.74  31188.   4077.   32.1   215.0  18.87   9318.5  0.634   230.5
 CRUISE   0.75  31188.  42211.  499.2  3659.0  16.07   7623.9  0.630   234.9
 DESCENT  0.33   1500.      0.   23.2   106.5  17.79      0.0  0.000   155.6
 LOITER   0.30   2177.   4710.   60.0   197.2  17.40   6804.7  0.683   123.8
 LANDING                        5528.6

 Block Time  =  9.570 hr
 Block Range = 4000.0 nm

 MISSION SUMMARY

 PHASE    MACH    ALT    FUEL   TIME    DIST   L/D    THRUST   SFC     Q
 =======  ====  ======  ======  =====  ======  =====  =======  =====  ======
 TAKEOFF  0.00      0.    635.   15.5  5618.4
 CLIMB    0.46  10000.    719.    3.1    13.7  18.17  22913.0  0.546   211.6
 ACCEL    0.51  10000.     63.    0.3     1.6  16.08  22498.1  0.568   265.0
 CLIMB    0.74  34628.   3702.   33.6   220.3  18.87   7905.0  0.621   196.1
```

```
CRUISE   0.75  34628.  42675.  611.8  4416.7  15.24   6405.1  0.617   200.1
DESCENT  0.30   1500.    706.   27.7   117.1  17.81      1.6951.029   123.7
LOITER   0.30   2252.   4123.   60.0   197.2  18.09   5167.9  0.787   123.5
LANDING                 4609.7
```

Block Time = 11.533 hr
Block Range = 4769.4 nm

MISSION SUMMARY

```
PHASE    MACH    ALT    FUEL   TIME    DIST   L/D   THRUST   SFC     Q
=======  ====  ======  ======  =====  ======  =====  =======  =====  ======
TAKEOFF  0.00      0.    635.   15.5  5331.3
CLIMB    0.46  10000.    688.    2.9    13.1  17.92  22913.0  0.546   211.6
ACCEL    0.51  10000.     61.    0.3     1.5  15.65  22498.1  0.568   265.0
CLIMB    0.74  35388.   3626.   34.0   222.0  18.87   7618.8  0.618   189.3
CRUISE   0.75  35388.  42887.  642.0  4618.8  15.02   6160.4  0.615   193.0
DESCENT  0.29   1500.    788.   28.7   118.9  17.82     31.1 55.973   117.8
LOITER   0.30   2259.   3935.   60.0   197.2  18.15   4870.3  0.797   123.5
LANDING                 4427.0
```

Block Time = 12.057 hr
Block Range = 4974.2 nm

MISSION SUMMARY

```
PHASE    MACH    ALT    FUEL   TIME    DIST   L/D   THRUST   SFC     Q
=======  ====  ======  ======  =====  ======  =====  =======  =====  ======
TAKEOFF  0.00      0.    635.   15.5  5054.4
CLIMB    0.46  10000.    658.    2.8    12.5  17.62  22913.0  0.546   211.6
ACCEL    0.51  10000.     58.    0.3     1.4  15.19  22498.1  0.568   265.0
CLIMB    0.75  36692.   3917.   39.3   258.6  18.88   7173.7  0.619   181.4
CRUISE   0.75  36692.  42715.  678.7  4865.8  15.09   5793.5  0.612   181.4
DESCENT  0.28   1500.    855.   30.2   123.1  17.82      8.9193.063   111.0
LOITER   0.30   2274.   3783.   60.0   197.2  18.04   4618.4  0.808   123.4
LANDING                 4243.0
```

Block Time = 12.780 hr
Block Range = 5261.5 nm

MISSION SUMMARY

```
PHASE    MACH    ALT    FUEL   TIME    DIST   L/D   THRUST   SFC     Q
=======  ====  ======  ======  =====  ======  =====  =======  =====  ======
TAKEOFF  0.00      0.    635.   15.5  4530.0
CLIMB    0.46  10000.    601.    2.6    11.4  16.86  22913.0  0.546   211.6
```

ACCEL	0.51	10000.	53.	0.3	1.3	14.19	22498.1	0.568	265.0
CLIMB	0.74	37770.	3398.	35.5	228.1	18.86	6791.7	0.616	168.9
CRUISE	0.75	37770.	43458.	739.8	5304.0	14.17	5453.3	0.612	172.2
DESCENT	0.27	1500.	874.	32.4	125.8	17.84	54.0	31.734	98.9
LOITER	0.30	2339.	3602.	60.0	197.1	17.00	4309.3	0.823	123.2
LANDING			3874.5						

Block Time = 13.767 hr
Block Range = 5670.7 nm

ZH-101: Mid-sized H_2 with two AE 3007

SUMMARY --- ACS OUTPUT: BWB H2 ZH-101

GENERAL FUSELAGE WING CANARD VTAIL
WG 38615. LENGTH 50.0 AREA 1000.0 0.0 50.0
W/S 38.6 DIAMETER 9.0 WETTED AREA 1642.4 0.0 100.5
T/W 0.49 VOLUME 1649.1 SPAN 77.5 0.0 10.0
N(Z) ULT 3.8 WETTED AREA 1484.1 L.E. SWEEP 34.5 89.4 45.0
CREW 1. FINENESS RATIO 5.6 C/4 SWEEP 30.0 0.0 41.3
PASENGERS 0. ASPECT RATIO 6.00 0.01 2.00
TAPER RATIO 0.20 0.00 0.35
ENGINE WEIGHTS T/C ROOT 0.12 0.00 0.10
T/C TIP 0.12 0.00 0.10
NUMBER 2. W WG ROOT CHORD 21.5 0.0 7.4
LENGTH 9.0 STRUCT. 11030. 28.6 TIP CHORD 4.3 0.0 2.6
DIAM. 3.2 PROPUL. 4600. 11.9 M.A. CHORD 14.8 0.0 5.4
WEIGHT 1500.0 FIX. EQ. 8154. 21.1 LOC. OF L.E. 17.1 0.0 42.6
TSLS 9500. FUEL 2769. 7.6
SFCSLS 0.11 PAYLOAD 10000. 25.9
ESF 1.000 OPER IT 2062. 5.3

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	93.	15.5	3039.6				
CLIMB	0.46	10000.	55.	1.6	7.1	12.77	10840.4	0.167	211.6
ACCEL	0.51	10000.	5.	0.2	0.8	10.36	10639.0	0.174	265.0
CLIMB	0.75	42596.	288.	23.4	147.5	17.23	2553.9	0.191	136.7
CRUISE	0.75	42596.	1640.	239.1	1713.9	17.06	2145.8	0.189	136.7
DESCENT	0.29	1500.	124.	30.3	130.7	16.59	0.9268.026		114.8
LOITER	0.30	1759.	551.	60.0	197.3	16.49	2192.3	0.250	125.3
LANDING				3810.9					

Block Time = 5.168 hr
Block Range = 2000.0 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	93.	15.5	2311.7				
CLIMB	0.46	10000.	42.	1.2	5.3	9.76	10840.4	0.167	211.6
ACCEL	0.51	10000.	4.	0.1	0.6	7.79	10639.0	0.174	265.0
CLIMB	0.75	48080.	243.	24.3	150.0	17.23	1964.4	0.191	105.1

```
CRUISE   0.75  48080.   1783.  341.1  2445.5  16.89   1629.1  0.189   105.1
DESCENT  0.25   1500.    101.   37.2   146.8  16.64     0.7240.550    87.3
LOITER   0.30   1808.    491.   60.0   197.3  14.73   1842.3  0.265   125.1
LANDING                         2948.2
```

Block Time = 6.990 hr
Block Range = 2748.3 nm

MISSION SUMMARY

```
PHASE    MACH     ALT    FUEL   TIME    DIST   L/D   THRUST   SFC      Q
======= ==== ====== ====== ===== ====== ===== ======= ===== ======
TAKEOFF  0.00      0.     93.   15.5  2238.8
CLIMB    0.46  10000.     41.    1.2     5.1   9.40  10840.4  0.167   211.6
ACCEL    0.51  10000.      4.    0.1     0.6   7.49  10639.0  0.174   265.0
CLIMB    0.75  48763.    237.   24.3   149.8  17.23   1901.2  0.191   101.8
CRUISE   0.75  48763.   1791.  354.8  2543.8  16.86   1572.9  0.189   101.8
DESCENT  0.25   1500.    103.   38.1   148.8  16.64     0.7240.550    84.2
LOITER   0.30   1818.    487.   60.0   197.3  14.35   1821.7  0.266   125.1
LANDING                         2853.1
```

Block Time = 7.234 hr
Block Range = 2848.1 nm

MISSION SUMMARY

```
PHASE    MACH     ALT    FUEL   TIME    DIST   L/D   THRUST   SFC      Q
======= ==== ====== ====== ===== ====== ===== ======= ===== ======
TAKEOFF  0.00      0.     93.   15.5  2462.1
CLIMB    0.46  10000.     45.    1.3     5.7  10.47  10840.4  0.167   211.6
ACCEL    0.51  10000.      4.    0.1     0.7   8.36  10639.0  0.174   265.0
CLIMB    0.75  46708.    253.   24.0   149.2  17.23   2097.7  0.191   112.3
CRUISE   0.75  46708.   1724.  308.3  2210.1  16.94   1745.5  0.189   112.3
DESCENT  0.26   1500.    138.   35.3   142.4  16.62     5.5 43.617    93.7
LOITER   0.30   1792.    498.   60.0   197.3  15.42   1890.1  0.262   125.2
LANDING                         3141.1
```

Block Time = 6.408 hr
Block Range = 2508.1 nm

MISSION SUMMARY

```
PHASE    MACH     ALT    FUEL   TIME    DIST   L/D   THRUST   SFC      Q
======= ==== ====== ====== ===== ====== ===== ======= ===== ======
TAKEOFF  0.00      0.     93.   15.5  2386.1
CLIMB    0.46  10000.     43.    1.3     5.5  10.12  10840.4  0.167   211.6
```

ACCEL	0.51	10000.	4.	0.1	0.7	8.08	10639.0	0.174	265.0
CLIMB	0.75	47365.	248.	24.1	149.3	17.23	2032.7	0.191	108.8
CRUISE	0.75	47365.	1756.	324.5	2326.3	16.91	1687.9	0.189	108.8
DESCENT	0.25	1500.	118.	36.2	144.6	16.63	1.1181.421		90.4
LOITER	0.30	1799.	494.	60.0	197.3	15.09	1865.2	0.264	125.1
LANDING				3044.9					

Block Time = 6.695 hr
Block Range = 2626.4 nm

ZH-201: Small H_2 with one AE 3007

SUMMARY --- ACS OUTPUT: BWB H2 ZH-201

```
    GENERAL          FUSELAGE                    WING  CANARD  VTAIL
 WG     16374.   LENGTH          30.0   AREA          550.0    0.0   20.0
 W/S      29.8   DIAMETER         7.5   WETTED AREA   879.4    0.0   15.9
 T/W      0.58   VOLUME         713.2   SPAN           57.4    0.0    7.7
 N(Z) ULT  3.8   WETTED AREA    651.4   L.E. SWEEP     34.5   89.4   45.0
 CREW       1.   FINENESS RATIO   4.0   C/4 SWEEP      30.0    0.0   42.6
 PASENGERS  0.                          ASPECT RATIO   6.00   0.01   3.00
                                        TAPER RATIO    0.20   0.00   0.35
   ENGINE            WEIGHTS            T/C ROOT       0.12   0.00   0.10
                                        T/C TIP        0.12   0.00   0.10
 NUMBER     1.                 W     WG ROOT CHORD     16.0    0.0    3.8
 LENGTH    9.0   STRUCT.    4408. 26.9  TIP CHORD       3.2    0.0    1.3
 DIAM.     3.2   PROPUL.    2150. 13.1  M.A. CHORD     11.0    0.0    2.8
 WEIGHT 1500.0   FIX. EQ.   6328. 38.6  LOC. OF L.E.    8.6    0.0   26.2
 TSLS    9500.   FUEL        824.  5.6
 SFCSLS   0.11   PAYLOAD    2000. 12.2
 ESF     1.000   OPER IT     664.  4.1
```

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	46.	15.5	2394.9				
CLIMB	0.46	10000.	24.	1.4	6.1	9.58	5462.1	0.166	211.6
ACCEL	0.51	10000.	2.	0.1	0.7	7.54	5368.9	0.172	265.0
CLIMB	0.65	42130.	99.	16.0	87.1	17.05	1275.1	0.176	105.0
CRUISE	0.65	42130.	341.	126.1	783.4	16.93	937.6	0.172	105.0
DESCENT	0.25	1500.	45.	32.4	122.6	16.51	13.0	9.405	90.3
LOITER	0.30	1786.	264.	60.0	197.3	15.01	1045.5	0.251	125.2
LANDING			2814.9						

Block Time = 3.193 hr
Block Range = 1000.0 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
=======	====	======	======	=====	======	=====	=======	=====	======
TAKEOFF	0.00	0.	46.	15.5	2220.3				
CLIMB	0.46	10000.	22.	1.3	5.7	8.76	5462.1	0.166	211.6
ACCEL	0.51	10000.	2.	0.1	0.7	6.89	5368.9	0.172	265.0
CLIMB	0.65	43725.	94.	16.2	87.6	17.05	1181.4	0.176	97.3

CRUISE	0.65	43725.	353.	141.6	880.0	16.90	865.4	0.172	97.3
DESCENT	0.24	1500.	43.	34.7	127.6	16.53	4.2	28.841	82.8
LOITER	0.30	1806.	259.	60.0	197.3	14.15	1020.8	0.253	125.1
LANDING				2606.0					

Block Time = 3.491 hr
Block Range = 1101.5 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	46.	15.5	2186.5				
CLIMB	0.46	10000.	22.	1.3	5.6	8.59	5462.1	0.166	211.6
ACCEL	0.51	10000.	2.	0.1	0.7	6.76	5368.9	0.172	265.0
CLIMB	0.65	44127.	94.	16.4	88.2	17.05	1158.9	0.176	95.4
CRUISE	0.65	44127.	355.	144.7	898.9	16.91	850.0	0.172	95.4
DESCENT	0.24	1500.	43.	35.2	128.9	16.53	2.3	53.296	81.3
LOITER	0.30	1811.	259.	60.0	197.3	13.96	1016.6	0.253	125.1
LANDING				2741.8					

Block Time = 3.553 hr
Block Range = 1122.2 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	46.	15.5	2086.9				
CLIMB	0.46	10000.	21.	1.2	5.3	8.09	5462.1	0.166	211.6
ACCEL	0.51	10000.	2.	0.1	0.6	6.37	5368.9	0.172	265.0
CLIMB	0.65	45076.	91.	16.4	87.7	17.05	1107.4	0.176	91.2
CRUISE	0.65	45076.	105.	44.6	277.4	16.97	817.1	0.172	91.2
DESCENT	0.24	1500.	53.	36.1	131.1	16.54	22.9	5.278	80.4
LOITER	0.30	1821.	257.	60.0	197.3	13.56	1009.1	0.254	125.1
LANDING				2611.0					

Block Time = 1.899 hr
Block Range = 502.1 nm

MISSION SUMMARY

PHASE	MACH	ALT	FUEL	TIME	DIST	L/D	THRUST	SFC	Q
TAKEOFF	0.00	0.	46.	15.5	2363.1				
CLIMB	0.46	10000.	24.	1.4	6.1	9.43	5462.1	0.166	211.6

ACCEL	0.51	10000.	2.	0.1	0.7	7.43	5368.9	0.172	265.0
CLIMB	0.65	42316.	97.	15.9	86.4	17.05	1263.8	0.176	104.1
CRUISE	0.65	42316.	122.	45.6	283.2	16.99	933.9	0.172	104.1
DESCENT	0.25	1500.	45.	32.5	123.2	16.52	12.9	9.454	90.4
LOITER	0.30	1786.	264.	60.0	197.3	15.01	1045.4	0.251	125.2
LANDING				2777.6					

Block Time = 1.851 hr
Block Range = 499.5 nm